

GEORGIA INSTITUTE OF TECHNOLOGY  
Engineering Experiment Station

*all*  
*Report file*

PROJECT INITIATION

Date: 2/25/71

Project Title: Evaluation of Treatment Plants by Tracer Methods

Project No.: A-1303

Project Director: Dr. G. G. Eichholz

Sponsor: U. S. Atomic Energy Commission

Effective January 15, 1971 Estimated to run until: January 14, 1972

Type Agreement: Contract No. AT-(40-1)-4156 Amount: \$ 37,000\*

Reports: Monthly Status Report - Letter type  
Final Draft  
Final

Contact Person: Technical  
Mr. Oscar M. Bizzell, Program Manager  
Environmental and Ocean Sciences  
Division of Isotopes Development  
U. S. Atomic Energy Commission  
Washington, D. C. 20546

Administrative  
Mr. Dent C. Davis  
Research Contracts Branch  
Oak Ridge Operations  
P. O. Box E  
Oak Ridge, Tennessee 37830

\*Plus \$2,243 to be  
contributed by Ga.  
Tech; E-600-702.

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Georgia Institute of Technology  
Engineering Experiment Station

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PROJECT TERMINATION

Date 3/22/72

PROJECT TITLE: Evaluation of Treatment Plants by Tracer Methods

PROJECT NO: A-1303-000

PROJECT DIRECTOR: Dr. G. G. Eichholz

SPONSOR: Atomic Energy Commission

TERMINATION EFFECTIVE: 1/15/72

CHARGES SHOULD CLEAR ACCOUNTING BY: 2/29/72

Closeout Actions Remaining:

1. Certified Expenditure Statement -  
due by April 15, 1972.
2. Report of Equipment Purchased or  
Fabricated - due by April 15, 1972.
3. Transfer of all charges after  
January 14, 1972 to Account A-1303-001.

Nuclear & Biological Sciences Division

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GEORGIA INSTITUTE OF TECHNOLOGY  
Engineering Experiment Station

PROJECT INITIATION

Date: 3/22/72

Project Title: Evaluation of Treatment Plants by Tracer Methods (Phase II)  
Project No.: A-1303-001  
Project Director: Dr. G. G. Eichholz and Dr. T. F. Craft  
Sponsor: Atomic Energy Commission  
Effective January 15, 1972 Estimated to run until: January 14, 1973  
Type Agreement: Contract No. AT-(40-1)-4156 Amount: \$39,913

Reports: Progress Report (with renewal proposal)  
Final Report (if project is not to be renewed)

Contact Persons: Dr. D. C. Davis or Mr. Earl M. Mason  
U. S. Atomic Energy Commission  
Oak Ridge Operations  
P. O. Box E  
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GEORGIA INSTITUTE OF TECHNOLOGY  
Engineering Experiment Station

PROJECT TERMINATION

Date December 6, 1973

PROJECT TITLE: **Evaluation of Treatment Plants by Tracer Methods (Phase II)**

PROJECT NO: **A-1303-001**

PROJECT DIRECTOR: **Dr. G. G. Eichholz and Dr. T. F. Craft**

SPONSOR: **Atomic Energy Commission**

TERMINATION EFFECTIVE: December 5, 1973

CHARGES SHOULD CLEAR ACCOUNTING BY: All charges are clear

**FINAL TECHNICAL REPORT: Completed**

**NUCLEAR & BIOLOGICAL SCIENCES**

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GEORGIA INSTITUTE OF TECHNOLOGY  
ATLANTA, GEORGIA 30332

SCHOOL OF  
NUCLEAR ENGINEERING

February 13, 1971

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Division  
Washington, D. C. 20545

First Monthly Progress Letter -- AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303

Dear Mr. Bizzell:

The above project was initiated as of January 15, 1971, though formal contract formalities are being completed only now. The initial month of effort has been devoted to getting the contract work under way.

Mr. Steven N. Hillsbaugh (B.S. in Ceramic Engineering) has been taken on as a full-time research assistant and Mr. Timothy M. Galbreth, a graduate student in nuclear engineering, as a part-time graduate research assistant.

A literature search has been started to determine if any other elements or radioisotopes than those previously considered should also be evaluated as potential tracers.

Some preliminary work has been done on neutron activation analysis of tap water and raw water to obtain background analyses and information on any trace element constituents that might interfere with the tracer work.

Experiments have been commenced on the production of suspendable organic particles, using fiber material as the starting point. A new ball mill has been ordered to overcome the limitations of the mill available to us at the moment.

Orders have been placed for operating supplies and tracer material for early delivery.

Some further discussions have been held with the staff of the Atlanta Water Pollution Control (Sewage Treatment) Division, since I last talked to you, and we have been assured of their active cooperation.

Respectfully submitted,

Geoffrey G. Eichholz  
Project Director

GGE:lsg

cc: H. L. Baker  
T. F. Craft  
C. J. Roberts  
Addressee (3 copies)  
Dr. H. M. Roth, Oak Ridge (6 copies)

*M. J. ...*  
*Becker*  
*Di ...*  
**GEORGIA INSTITUTE OF TECHNOLOGY**  
ATLANTA, GEORGIA 30332

**SCHOOL OF  
NUCLEAR ENGINEERING**

March 11, 1971

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Division  
Washington, D. C. 20545

Second Monthly Progress Letter -- Feb. 11 - March 10, 1971  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303

Dear Mr. Bizzell:

A number of elements have been selected for possible use as tracers, and those not already on hand have been ordered. Work has been carried out on indium, bromine, and scandium to determine the practical limits of sensitivity to neutron activation under the actual conditions to be encountered during this study. From the standpoint of nuclear activation properties, indium appears to be an excellent choice. Other considerations such as sorption losses in a flow system have not yet been evaluated.

Inorganic particulate tracers involving indium and scandium have been prepared. The tracers were added to a commercially available glass frit, melted, and then ground. The tracer is leached from the particles at a very low rate initially, but more extensive investigation is required to determine if the rate of loss actually approaches zero after some period of time.

A kaolin sample has also been labeled with indium, and rate of loss is about the same as with the glass. A clay would be preferable to glass, as the clay can be calcined much more rapidly than the glass can be melted.

The preparation of organic particulates is proving (as expected) to be more difficult than the preparation of inorganic materials. The major problem so far has been to achieve small enough particles of an organic substance that is sufficiently non-biodegradable to survive for a long time under the strenuous degradative conditions of a waste treatment plant.


Arrangements have been made with the City of Atlanta Water Pollution Control Division for study of flows in some selected sewer lines. The initial experiment will be carried out in a small drainage basin in western Atlanta, served by the Sandy Creek Water Pollution Control Plant. This is one of the smaller Atlanta treatment plants (1 mgd design capacity) and should provide good experience for later studies involving flows as large as perhaps 30 or 40 mgd. This work is expected to be done in the near future.



Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Division  
AEC Contract No. AT-(40-1)-4156  
March 11, 1971  
Page 2

Literature studies have been carried on concurrently to maintain an up-to-date bibliography on relevant publications.

Respectfully submitted,

  
Geoffrey G. Eichholz  
Project Director

GGE:lsg

cc: H. L. Baker  
T. F. Craft  
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Dr. H. M. Roth, Oak Ridge (5 copies)

GEORGIA INSTITUTE OF TECHNOLOGY  
ATLANTA GEORGIA 30332

SCHOOL OF  
NUCLEAR ENGINEERING

April 14, 1971

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Division  
Washington, D. C. 20545

Third Monthly Progress Letter -- March 11 - April 10, 1971  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303

Dear Mr. Bizzell:

During the month, more of the elements previously selected have been tested to determine their suitability as tracers for the purposes of this project. Indium, bromine, and scandium had previously been evaluated, and work has now started on cerium, cobalt, chromium, tungsten, and molybdenum. Attempts are being made to attach these elements to organic fibers. Chromium appears to work well; experiments with the others are not far enough advanced to evaluate.

It has now been found that tracer can be added to glass by melting bottle glass and stirring in the metallic oxide. This is much faster than using glass frits as previously reported, and there is no obvious difference in the resulting tracer particles after the glass has been powdered in a ball mill.

A preliminary study of flow rates and conditions has been made at the Sandy Creek Water Pollution Control Plant of the City of Atlanta. Tracer was poured into a sewer at point "A" shown on the attached map and samples were collected at the grit chamber of the treatment plant, approximately 1.2 miles away. The tracer consisted of sodium bromide plus a small amount of fluorescent dye. This was followed by a red dye in sufficient quantity for visual observation. The fluorescent dye was invisible to the eye but was readily detected by a continuous-flow fluorometer. Samples were collected at five minute intervals until the fluorometer indicated the presence of the dye. The sampling interval was then reduced to one minute. Sampling was continued until the bright red dye arrived.




Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Division  
AEC Contract No. AT-(40-1)-4156  
April 14, 1971  
Page 2

All the samples collected were subsequently analyzed by neutron activation and it was found that the maximum tracer content occurred at a time consistent with the fluorometer readings. It was apparent, however, that insufficient bromide was used, as the maximum was not high enough above background for proper statistical significance. This experiment will be repeated within the next few days.

I hope to discuss this work with you in person when you are visiting us next week.

Respectfully submitted,

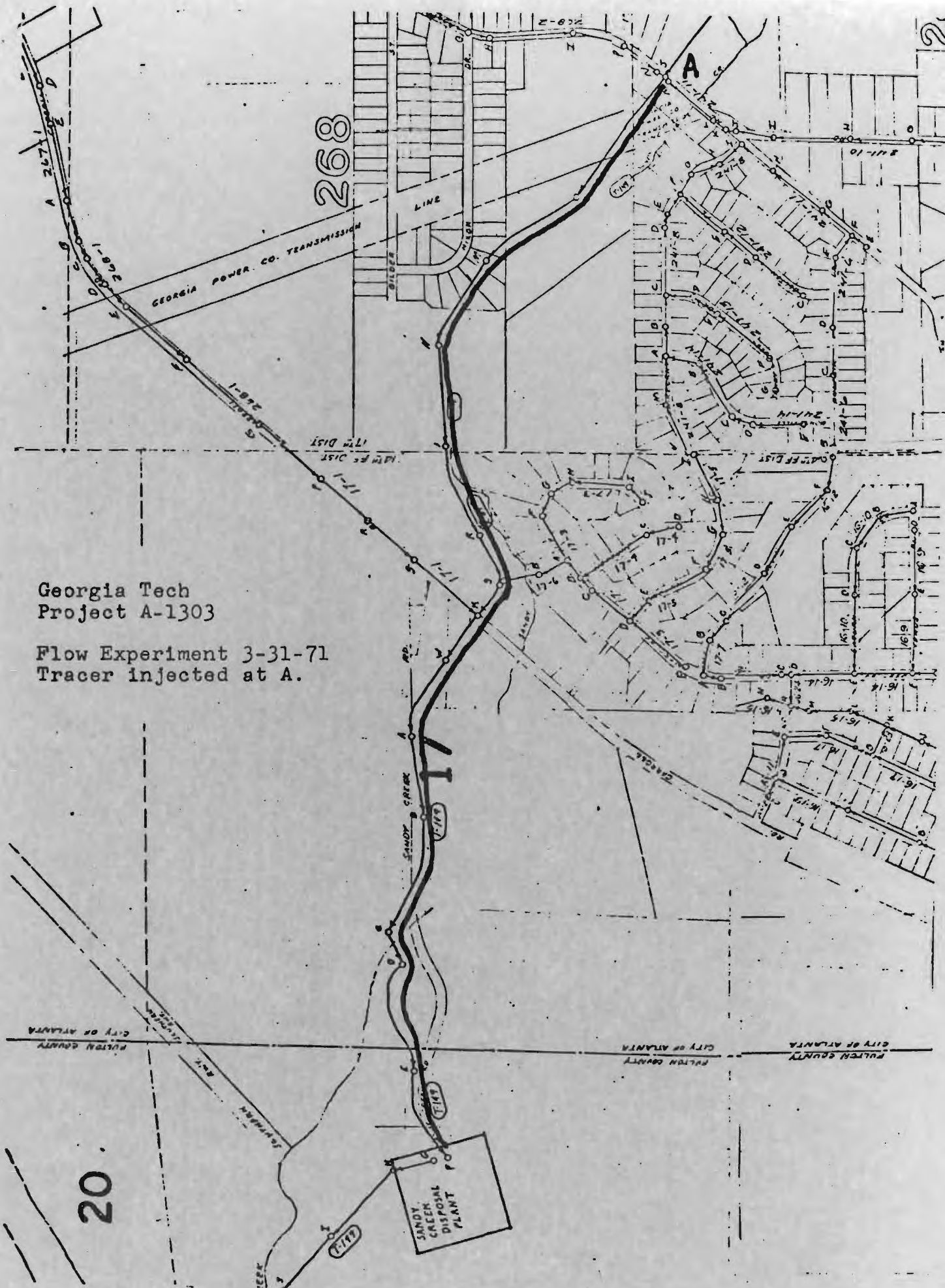
  
Geoffrey G. Eichholz  
Project Director

GGE:lsg  
Enclosure

cc: H. L. Baker  
T. F. Craft  
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Flow Experiment 3-31-71  
Tracer injected at A.

20





GEORGIA INSTITUTE OF TECHNOLOGY  
ATLANTA GEORGIA 30332

SCHOOL OF  
NUCLEAR ENGINEERING

May 12, 1971

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Division  
Washington, D. C. 20545

Fourth Monthly Progress Letter -- April 11 - May 10, 1971  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303

Dear Mr. Bizzell:

A second, more comprehensive field trial has been performed at the Sandy Creek Water Pollution Control plant mentioned in our letter of April 14. With the experience gained in the first run, it was possible to plan a more detailed and meaningful test. A brilliant red dye for visual observation was included with the tracer mixture which consisted of indium sulfate and sodium bromide.

Samples were collected at the inlet to the grit chamber and at six locations in the sedimentation basin, following tracer injection at the same manhole as before, about 1.2 miles away. Both indium and bromine were detected at levels appropriate to the situation at the grit chamber and at one inlet to the sedimentation basin. It was clearly shown that flow through the sedimentation basin was not uniform, and the residence time much shorter than expected, although the exact situation has not been fully elucidated. Another trial will be carried out at this plant in the next few days.


The Flint River Waste Water Treatment plant of the Clayton County Water Authority is having a severe problem with their trickling filter, which is badly clogged and affording a BOD reduction of nearly zero. An application of dye and tracer revealed a hole through this filter so that tracer was detected after seven minutes, although a delay of about 2 hours was anticipated. This filter is scheduled to be cleaned within the next six or eight weeks and further tests are planned for before and after cleaning.

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Division  
AEC Contract No. AT-(40-1)-4156  
May 12, 1971  
Page 2

Laboratory work is continuing on the labeling of organic particles and their use in determining the rate of sedimentation under quiescent conditions.

Dr. T. F. Craft presented a paper, "Scandium Distribution in Some Southeastern Clays" at the Annual Meeting of the Georgia Academy of Science, Carrollton, Georgia, April 24, 1971.

Respectfully submitted,

  
Geoffrey G. Eichholz  
Project Director

GGE:lsg

cc: -H. L. Baker  
T. F. Craft  
C. J. Roberts  
Addressee (3 copies)  
Dr. H. M. Roth, Oak Ridge (5 copies)

*Al Becker  
Steve Brown*

GEORGIA INSTITUTE OF TECHNOLOGY  
ATLANTA, GEORGIA 30332

SCHOOL OF  
NUCLEAR ENGINEERING

June 10, 1971

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Division  
Washington, D. C. 20545

Fifth Monthly Progress Letter -- May 11 - June 10, 1971  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303

Dear Mr. Bizzell:

Both laboratory and field work have been continued during the subject period. The laboratory work has involved efforts to label particulates with appropriate cations. Cobalt is currently a prime candidate, with completion of evaluation anticipated within a couple of weeks. One major advantage of cobalt over indium is the matter of cost, though this is offset to some extent by its lower sensitivity.

The data from the Sandy Creek test previously reported have been recalculated, and there is an anomalous situation with respect to influent concentrations. As an early test, however, the results still seem meaningful.

The Clayton County Flint River Plant is still in very poor condition and cleaning operations are not scheduled until June 29-30. A test was made there by adding indium plus a dye to the trickling filter dosing box and sampling at the effluent points. The secondary clarifiers were also included by sampling the influent and effluent of both basins. For comparison, this will be repeated following the cleaning operation.

The City of Atlanta Airport Plant is a trickling filter plant operating in normal fashion. A test was made there with samplings at points corresponding to those of the Clayton County plant. The experimental results from this test have been plotted and a copy of the plot is attached.

The latter two tests are considered to be very successful due, at least in part, to growing experience with sampling techniques and greater ease in the activation analyses due to improved counting arrangements.

It is proposed to submit a paper on some of these aspects for the October meeting of the ANS.

Respectfully submitted,

Geoffrey G. Eichholz  
Project Director

GGE:lsg  
Enclosure

*6/14/71*

cc: H. L. Baker,  
T. F. Craft,  
C. J. Roberts

Addressee (3 copies),  
Dr. H. M. Roth, Oak Ridge (5 copies),

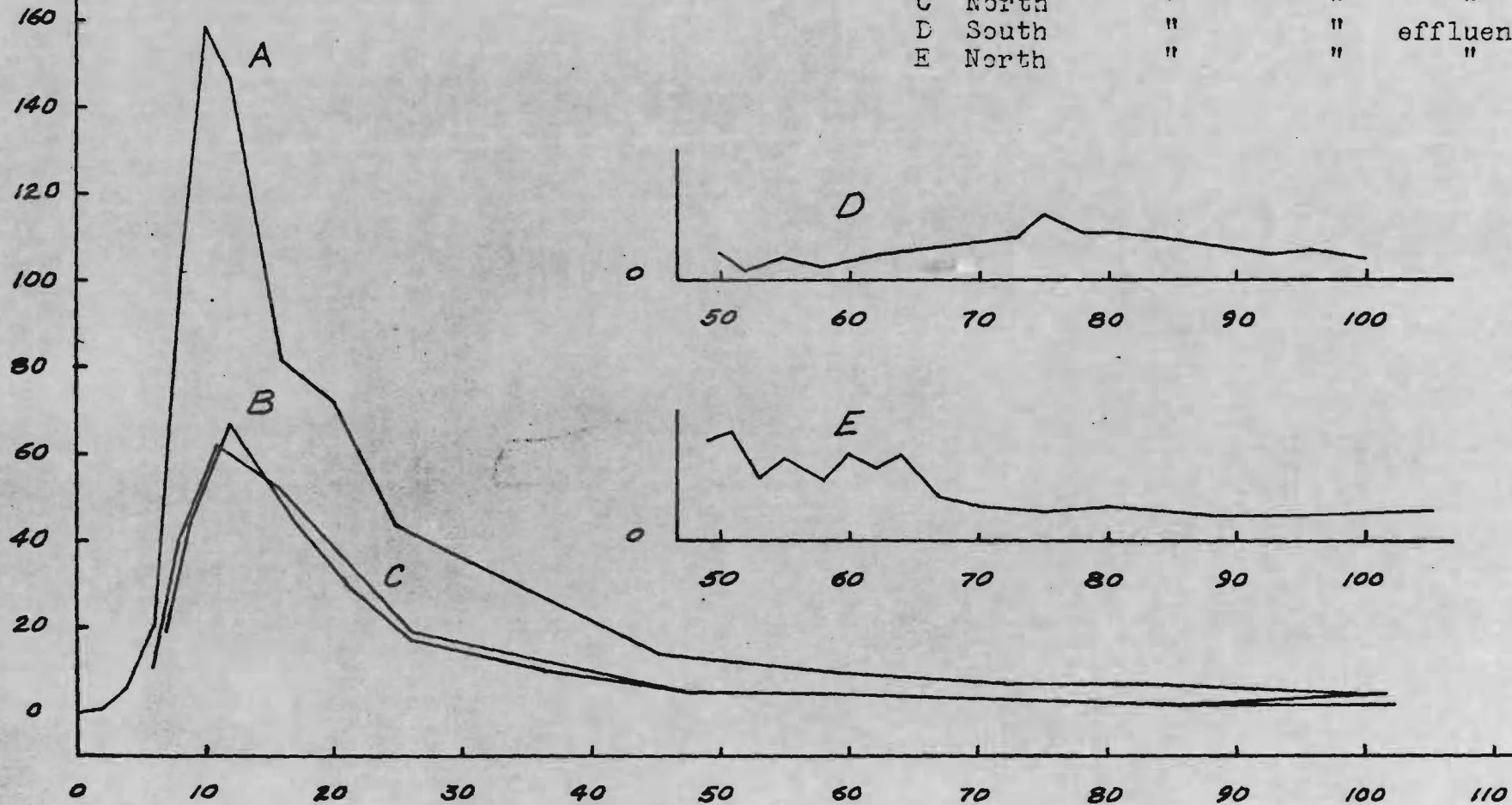


City of Atlanta - Airport WPC Plant  
Test of May 20, 1971

Sampling points:

- A Trickling filter effluent
- B South sedimentation basin influent
- C North " " "
- D South " " effluent
- E North " " "

Indium (parts per billion)



Time (minutes)

*H. L. Baker*  
*Al Camp*



GEORGIA INSTITUTE OF TECHNOLOGY  
EXPERIMENT STATION

225 North Avenue, Northwest · Atlanta, Georgia 30332

July 13, 1971

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Division  
Washington, D. C. 20545

Sixth Monthly Progress Letter -- June 11 - July 10, 1971  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303

Dear Mr. Bizzell:

Experiments on the labeling of sewage sludges have been performed. Cobalt, which was mentioned in our last report has received attention, but has definite disadvantages. Cobalt-60 has a long half life, and the correspondingly low specific activity makes for poor sensitivity. Cobalt-60<sup>m</sup> has an inconveniently short half-life of 10.5 minutes, but could be used if necessary. Indium appears much more favorable and will be tested July 13 in a plant trial at the Sandy Creek plant.

During the evaluation of labels for sludge, it was found that sedimentation data could be obtained very conveniently by placing a container of sludge carrying an activated tracer on a detector and measuring activity as a function of time. This information can be used to determine the efficiency of sedimentation, and to predict the performance of a basin at different overflow rates. The difference between quiescent and flowing conditions must be taken into consideration, however.

Cleaning of the trickling filter at the Clayton County Flint River Plant was attempted by chemical means, but was not successful. Mechanical cleaning by removing and washing the stone is presently in progress. When operating conditions are returned to normal, a tracer study will be made for comparison with our earlier study made when the plant was in very poor condition.

Respectfully submitted,

Geoffrey G. Eichholz  
Project Director

GGE:lsg

cc: H. L. Baker  
T. F. Craft  
B. J. Dasher  
Addressee (3 copies)  
Dr. H. M. Roth, Oak Ridge (5 copies)



GEORGIA INSTITUTE OF TECHNOLOGY  
ATLANTA, GEORGIA 30332

SCHOOL OF  
NUCLEAR ENGINEERING

August 12, 1971

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Seventh Monthly Progress Letter - July 11 - August 10, 1971  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303

Dear Mr. Bizzell:

During the period under review, a field trial utilizing sewage sludge labeled with indium has been made at the Sandy Creek WPC Plant in Atlanta. Three gallons of sludge, boiled with indium tracer solution, were dumped into the inlet of the sedimentation basin. Samples collected at the outlet were filtered and the sludge retained on the filter paper was activated and counted. Additional unfiltered liquid samples were also activated and counted. A very distinctive pattern emerged as shown on the attached copy of an activity plot. It appears that some pattern of recirculation existed within the basin to cause the periodicity of sludge indium concentrations. The pattern of the liquid samples is not as clear, but follows in a manner similar to that of the sludge.

From an aesthetic standpoint, boiling of sewage sludge leaves much to be desired, so a second trial has been made using sludge that was stirred with the tracer solution but not heated. This took place on August 10, and analyses of the collected samples have not yet been made.

Laboratory experiments on the labeling of some other organic solids have been performed. Oatmeal and grits have been labeled with indium, cobalt, tantalum, and scandium under various conditions. It has been found that these materials settle in a manner similar to a biological sludge if they are first macerated in a blender and added to a large volume of water.


A mathematical study of the relation of particle size distribution to settling rate has been undertaken and the validity of the results is being evaluated by laboratory experiments.

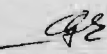


Mr. Oscar M. Bizzell  
AEC Contract No. AT-(40-1)-4156  
August 12, 1971  
Page 2

The Clayton County Flint River Plant has not yet recovered sufficiently from its difficulties to be considered in normal operation. It is hoped that the follow-up test in this plant can be performed in the near future.

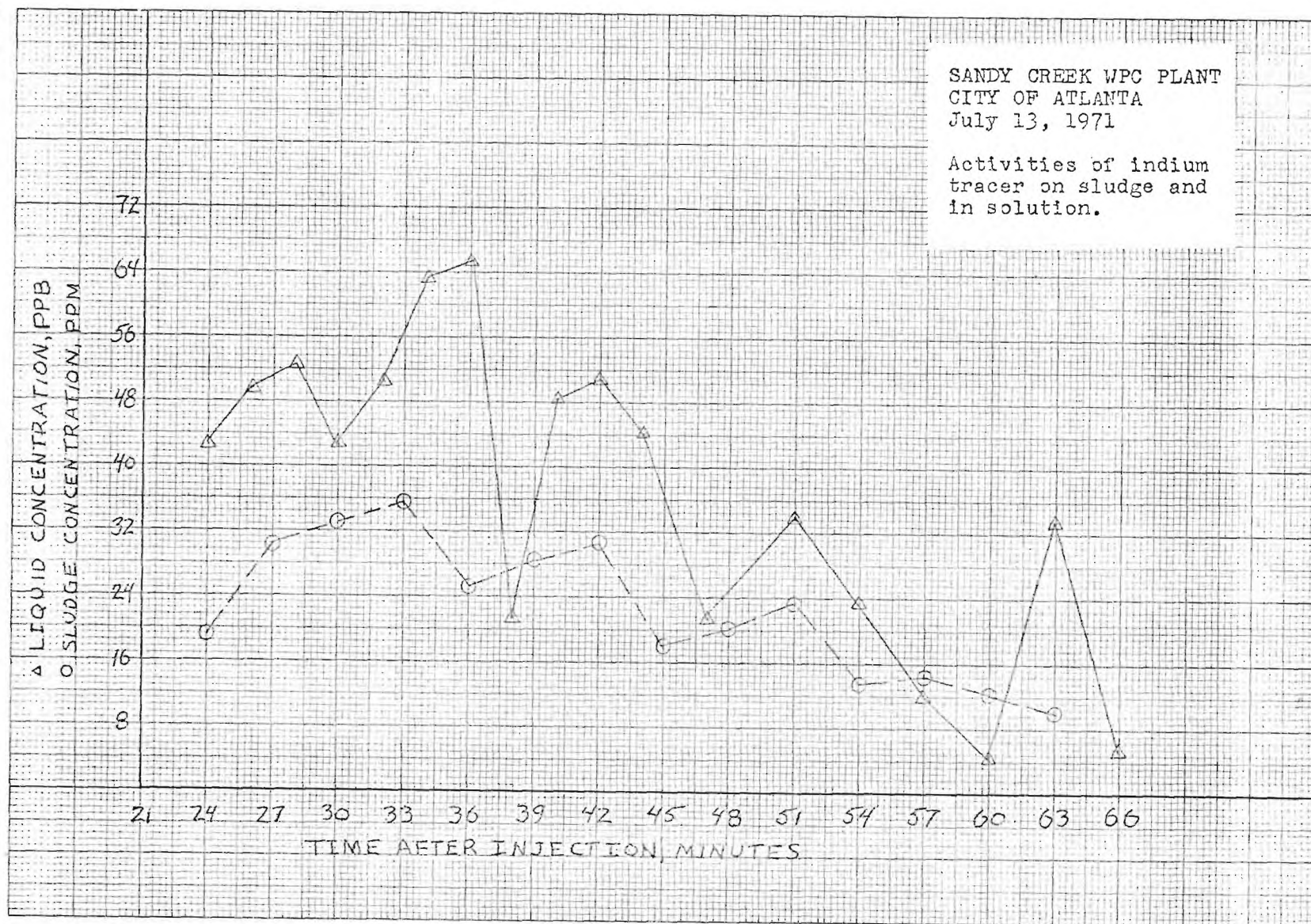
Respectfully submitted,

  
Geoffrey G. Eichholz  
Project Director

  
T. F. Craft  
Principal Investigator

GGE:TFC:lsg  
Enclosure

cc: H. L. Baker  
B. J. Dasher  
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GEORGIA INSTITUTE OF TECHNOLOGY  
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SCHOOL OF  
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September 20, 1971

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Eighth Monthly Progress Letter - August 11 - September 10, 1971  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303

Dear Mr. Bizzell:

On August 10, a second run using labeled sludge was carried out at the Atlanta Sandy Creek WPC Plant. The sludge was stirred with tracer but not heated. Although the indium tracer became attached to the solid particles as desired, the results were considerably different from those of the first run. The attached sheet illustrated the second set of results, and does not show the periodic variation of tracer concentration previously seen. The irregularity of the curves appears to be genuine; the differences are much greater than the uncertainties due to errors in sampling and analysis. No satisfactory explanation for this behavior is available at present, but the matter is under active consideration.

The Clayton County WPC plant has finally been returned to normal operation following chemical and mechanical cleaning of the trickling filter. A tracer run using indium was made on August 24, so that the "normal" pattern could be compared with the earlier results. The two runs were almost identical, a finding that was quite unexpected. It appears that the hydraulic situation in both instances was very similar, with little difference in hold-up time between free percolation over cleaned stone, and flow through a few established channels as occurred during the plugged condition.

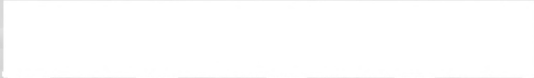
Notes have been prepared for delivery of a 45 minute paper "Tracer Methods for Evaluation of Waste Treatment Processes" at the Annual Conference




Mr. Oscar M. Bizzell  
AEC Contract No. AT-(40-1)-4156  
September 20, 1971  
Page 2

of the Georgia Water Pollution Control Association. This conference will be held at Augusta, Georgia, September 12-15.

Respectfully submitted,

  
Geoffrey G. Eichholz  
Project Director

  
T. F. Craft  
Principal Investigator

GGE:TFC:lsg  
Enclosure

cc: H. L. Baker  
B. J. Dasher  
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Dr. H. M. Roth, Oak Ridge (5 copies)

TRACER CONCENTRATION

PPB

70

60

50

40

30

20

10

0

SUPERNATANT

PPM

12

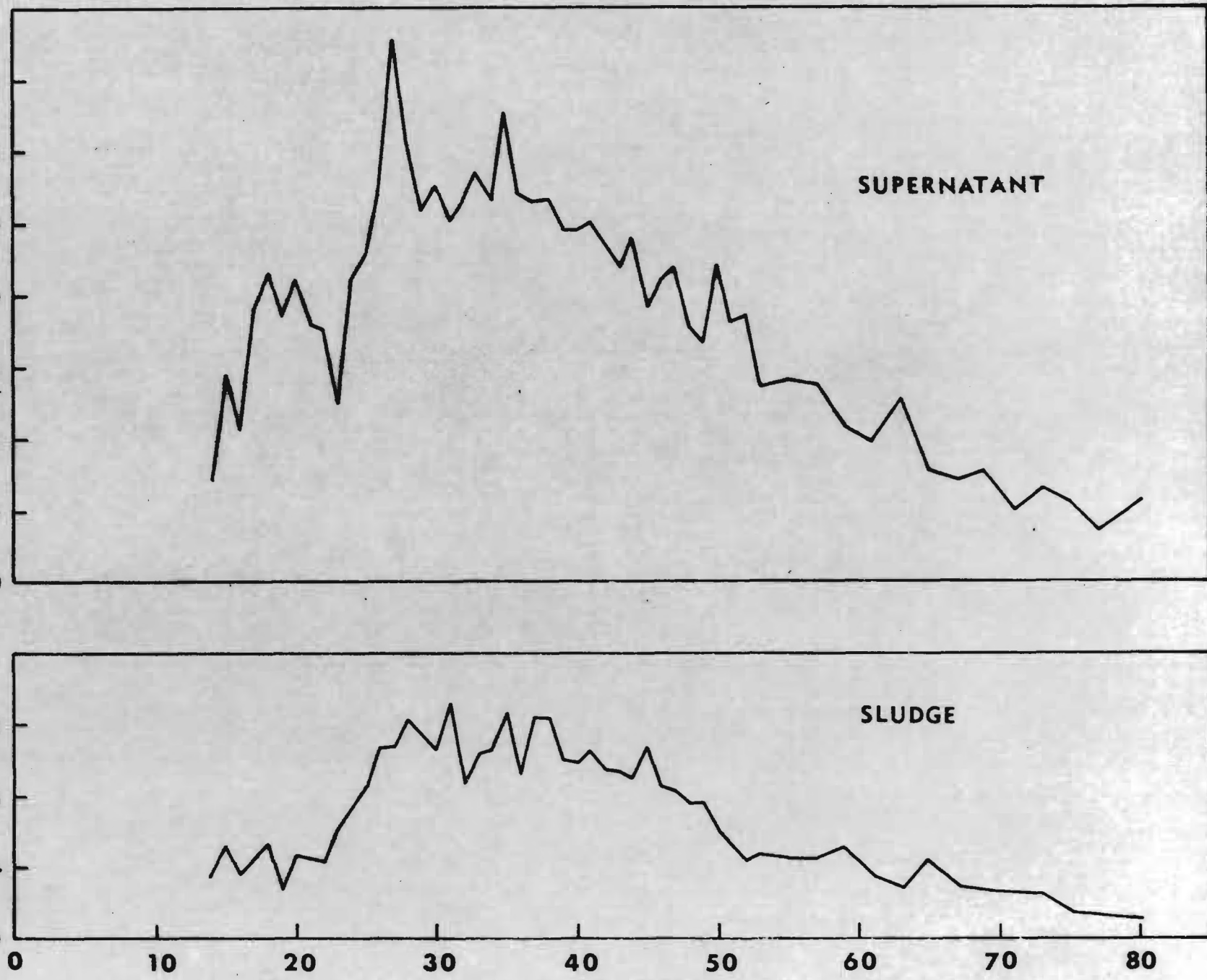
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SLUDGE

MINUTES AFTER TRACER INJECTION





GEORGIA INSTITUTE OF TECHNOLOGY  
EXPERIMENT STATION 225 North Avenue, Northwest Atlanta, Georgia 30332

October 13, 1971

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Ninth Monthly Progress Letter - Sept. 11 - October 10, 1971  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303


Dear Mr. Bizzell:


In the laboratory, experiments on the labeling of colloidal inorganic particles have been carried out. Vermiculite was used as the carrier and indium as the tracer element. This material has not yet been used in the field, but the laboratory work looks very satisfactory.

The possible use of manganese as a tracer is being investigated because of its relatively low price. There is an appreciable amount of manganese in local waters and the level of this background is being determined. A number of activation analyses for manganese have been carried out on river water samples from above and below Atlanta, and from other locations.

A paper, "Tracer Methods for Evaluation of Waste Treatment Processes," was delivered by T. F. Craft at the Annual Conference of the Georgia Water Pollution Control. Judging by the questions which followed the presentation and later comments by conferees, the paper was well received. It was suggested that the tracer technique be tried in a new waste treatment plant located at the Pabst Brewing Co. in Perry, Georgia. This facility is achieving exceptionally high efficiencies (about 99%) and the reasons for this are not known. This plant will be kept in mind for possible study when our techniques have been more highly developed.

Respectfully submitted,

  
Geoffrey G. Eichholz  
Project Director

  
T. F. Craft  
Principal Investigator

GGE:TFC:lsg

cc: H. L. Baker  
G. W. Leddicotte  
Address (3 copies)  
Dr. H. M. Roth, Oak Ridge





GEORGIA INSTITUTE OF TECHNOLOGY

EXPERIMENT STATION

225 North Avenue, Northwest Atlanta, Georgia 30332

November 22, 1971

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Commission  
Washington, D. C. 20545


Tenth Monthly Progress Letter - October 11, 1971 - November 10, 1971  
AEC Contract No. AT - (40 -1) - 4156  
Our Project No. A - 1303


Dear Mr. Bizzell:

Plans have been made to demonstrate the use of a radioisotope tracer in a sewage treatment plant. This technique will be compared with the post-sampling activation procedure that we have previously employed, so the relative merits of each can be determined. Permission to carry out the radioisotope experiment was readily granted by the Atlanta authorities, but permission of the Radioisotopes Committee of Georgia Tech is also necessary to remove a radioactive material from the campus. Additionally, the approval of the Georgia State Department of Health must be obtained. While permission will probably be granted, the extreme sensitivity of everyone to the release of radioactivity to the environment (even at the near MPC level) has created delays.

The possible use of some less expensive tracer materials for use in the post-sampling activation procedure has been considered. The cost factor is important in such cases as activated sludge basins, where the sludge is likely to absorb the tracer unless it is added in large quantities. Manganese is a suitable material from the nuclear standpoint, but is already present in most waters in this area. Analyses of a number of waters for manganese have been made, and the results are shown in Table I.

Respectfully submitted,

  
Geoffrey G. Eichholz  
Project Director

  
T. F. Craft  
Principal Investigator

GGE:TFC:jah

cc: H. L. Baker  
G. W. Leddicotte  
Dr. H. M. Roth, Oak Ridge (3 copies)

Table I Manganese Concentrations in Various  
Water Samples. (parts per billion)

Source	Suspended	Dissolved
Chattahoochee River		
Above Atlanta	$41.8 \pm 0.6$	$21.0 \pm 2.0$
Below Atlanta	$37.7 \pm 0.2$	$40.3 \pm 2.8$
Clayton County Flint River		
Sewage Treatment Plant		
influent	$24.9 \pm 0.1$	$129 \pm 3.0$
Atlanta tap water	$0.98 \pm 0.02$	$5.40 \pm 1.0$
Winston Salem, N.C. Tap Water	$1.54 \pm 0.03$	$31.2 \pm 1.8$
Distilled Water	$0.01 \pm .005$	$7.86 \pm 1.21$
Broad River, Columbia S. C.	$9.87 \pm 0.07$	$47.3 \pm 2.8$
Dalton, Ga. treatment plant		
influent	$1.03 \pm 0.02$	$4.26 \pm 0.03$
effluent	$4.35 \pm 0.05$	$14.6 \pm 1.6$
Utoy Creek treatment plant		
influent	$7.63 \pm 0.05$	$29.2 \pm 1.8$
effluent	$5.96 \pm 0.04$	$26.1 \pm 1.8$



GEORGIA INSTITUTE OF TECHNOLOGY  
EXPERIMENT STATION

225 North Avenue, Northwest - Atlanta, Georgia 30332

December 13, 1971

Mr. Oscar Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Eleventh Monthly Progress Letter -- November 11 - December 10, 1971  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303

Dear Mr. Bizzell:

Laboratory work is continuing on the possible use of tantalum as a tracer. We regard indium as the most useful single isotope, but others are needed for situations requiring more than one isotope. Some experiments have also been performed on the determination of mercury at very low levels in water.

The major experiment of this period was a field test at the South River WPC plant of the City of Atlanta. This plant was selected because it utilizes the activated sludge process of sewage treatment. The situation in an activated sludge basin is completely different from that in the sedimentation basins we have previously studied. In the activated sludge basin, the fluid contains a high level of suspended solids (around 2500 mg/l) and is kept in vigorous agitation by the air being injected. In our test the usual combination of dye (500 grams) and indium (24 grams) was dumped into the tank, but the dye color was lost to sight within about one minute. Even without visual indication, samples were taken at two positions in the tank, and were satisfactorily analyzed. As the flow regime within the basin is nearly that of complete mix, further work will be required to ascertain the significance of the results.

Yours truly,

T. F. Craft  
Principal Investigator

TFC:lsg

cc: H. L. Baker  
G. W. Leddicotte  
Addressee (3 copies)  
Dr. H. M. Roth (Oak Ridge, 6 copies)  
G. G. Eichholz





GEORGIA INSTITUTE OF TECHNOLOGY  
EXPERIMENT STATION 225 North Avenue, Northwest Atlanta, Georgia 30332

January 19, 1972

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Twelfth Monthly Progress Letter - December 11, 1971 - January 10, 1972  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303

Dear Mr. Bizzell:

Permission to carry out a field experiment with radioactive material has now been received from all authorities involved. These are the City of Atlanta, the Georgia Tech Radioisotopes Committee, and the Georgia State Health Department. The delay involved with these administrative matters is one disadvantage of radioactive tracers as compared with the post sampling activation technique. We will perform the radiotracer experiment at the City of Atlanta Sandy Creek Plant as soon as the weather permits.

The preparation of an annual report has begun. After considering the data already in hand, it appears that at least two papers can be written. One paper can cover the general features of the work, and a second will involve the theoretical aspects of the hydraulics and biological functioning of the trickling filters that we have studied. Our trickling filter data are distinctly contrary to data in the literature, and should be of considerable interest to treatment plant designers as well as theoreticians.

Yours truly,

G. G. Eichholz  
Project Director

T. F. Craft  
Principal Investigator

GGE:TFC:lsg

cc: H. L. Baker  
G. W. Leddicotte  
H. M. Roth, Oak Ridge



EXPERIMENT STATION 225 North Avenue, Northwest Atlanta, Georgia 30332

February 18, 1972

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Commission  
Washington, D. C. 20545


Thirteenth Monthly Progress Letter  
January 11, 1972 - February 10, 1972  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303


Dear Mr. Bizzell:

An experiment involving the use of a radioactive tracer has been carried out at the Sandy Creek WPC Plant of the City of Atlanta. Fifteen hour sodium-24, prepared in the Georgia Tech Research Reactor, was used to study flow patterns in a sedimentation basin. Field instrumentation consisted of a scintillation detector immersed in the tank outlet and a single channel analyzer which was used to examine discrete collected samples. With the information thus available, it was possible to tell immediately the effect of movement of the sludge collecting mechanism on the flow pattern of the tank. There are considerable implications from this experiment for the operation of basins, and a very detailed study of the data is being made.

In conjunction with preparation of the annual report, all of the data collected so far have been reviewed in detail in order to extract the maximum information from the work already performed. It appears that several additional experiments can be carried out which will help expand our understanding of some of the processes already studied. The completion of the annual report is expected within the next few days, and the draft will be forwarded promptly.

Yours truly,

  
G. G. Eichholz  
Project Director

  
T. F. Craft  
Principal Investigator

GGE:TFC:lsg

cc: H. L. Baker  
G. W. Leddicotte  
H. M. Roth, Oak Ridge (3 copies)  
Addressee (3 copies)



GEORGIA INSTITUTE OF TECHNOLOGY  
EXPERIMENT STATION 225 North Avenue, Northwest Atlanta, Georgia 30332

A-1303

March 14, 1972

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Fourteenth Monthly Progress Letter -- February 11 - March 10, 1972  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303

Dear Mr. Bizzell:

The major effort of the month has been the preparation and completion of the annual report. This involved not only a description of the work performed but a detailed evaluation of the significance of the data acquired. It now appears that two of the experiments performed in the field have very important implications, and both need to be investigated farther.

The first is the matter of flow-through time of the trickling filter at the Clayton County WPC plant. The findings are entirely different from what one would expect from reading the pertinent, readily available literature. Consequently, a more extensive literature search has been started to see if any results similar to ours have ever been reported. It is expected that a major paper will result from this effort.

The second unexpected finding was the pattern of recirculation in the Sandy Creek WPC plant sedimentation basin. It was recognized all along that flow patterns in an open tank, particularly an overloaded one, will be far from uniform, but the periodicity of the fluctuations in tracer concentration were notable. An extensive involvement with this single problem does not seem appropriate to the goals of the present contract, so a proposal to investigate this matter is being prepared as a separate project.

In addition to the paper on the theory of trickling filters, we expect to publish two other papers. One will cover the work from the nuclear technology viewpoint and the other from the standpoint of utility of the techniques to people in the water and wastewater field.



Mr. Oscar M. Bizzell  
AEC Contract No. AT-(40-1)-4156  
March 14, 1972  
Page 2

T. F. Craft has been invited to present a seminar on the subject of this work at the University of Georgia, Athens, on April 13. Besides a formal presentation of data he will also consult with several interested investigators and students on tracer methods.

Yours truly,

\_\_\_\_\_  
Geoffrey G. Eichholz  
Project Director

\_\_\_\_\_  
T. F. Craft  
Principal Investigator

TFC:lsg

cc: H. L. Baker  
G. W. Leddicotte  
Addressee (3 copies)  
Dr. H. M. Roth, Oak Ridge (3 copies)



GEORGIA INSTITUTE OF TECHNOLOGY  
EXPERIMENT STATION 225 North Avenue, Northwest Atlanta, Georgia 30332

April 18, 1972

Mr. Oscar M. Bizzell  
Division of Isotopes Development  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Fifteenth Monthly Progress Letter--March 11 - April 10, 1972  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303-001

Dear Mr. Bizzell:

The South River WPC plant of the City of Atlanta was the location at which the major field experiment of the period was carried out. Flow through one of four activated sludge basins was studied by injecting indium tracer and sampling at five different points.


When the collected samples were analyzed, it was found that the precision of replicate analyses was very erratic as shown by the attached graphs. At the one-quarter position of the tank, the best results were obtained. It is believed that conditions in the tank were such that mixing is very nearly complete, a situation different from the sedimentation basins we have previously studied.


Additionally, the sludge adsorbs the tracer, and it therefore becomes necessary to obtain identical amounts of sludge in each sample. This is rather difficult as the sludge settles very rapidly in the sample collector from which the replicates are drawn. A repetition of this experiment is planned, and much greater effort will be directed to obtaining more reliable samples.

Laboratory experiments on the labeling of organic substrates are continuing. Efforts to effectively and firmly attach molybdenum, indium, and chromium to wool have been made, and the technique developed may prove useful in the field.

Plans have been made to measure infiltration rates in a long sewer line leading into the Utoy Creek WPC plant, and the experiment will be carried out within the next few days.

Yours truly,

  
G. G. Eichholz  
Project Director

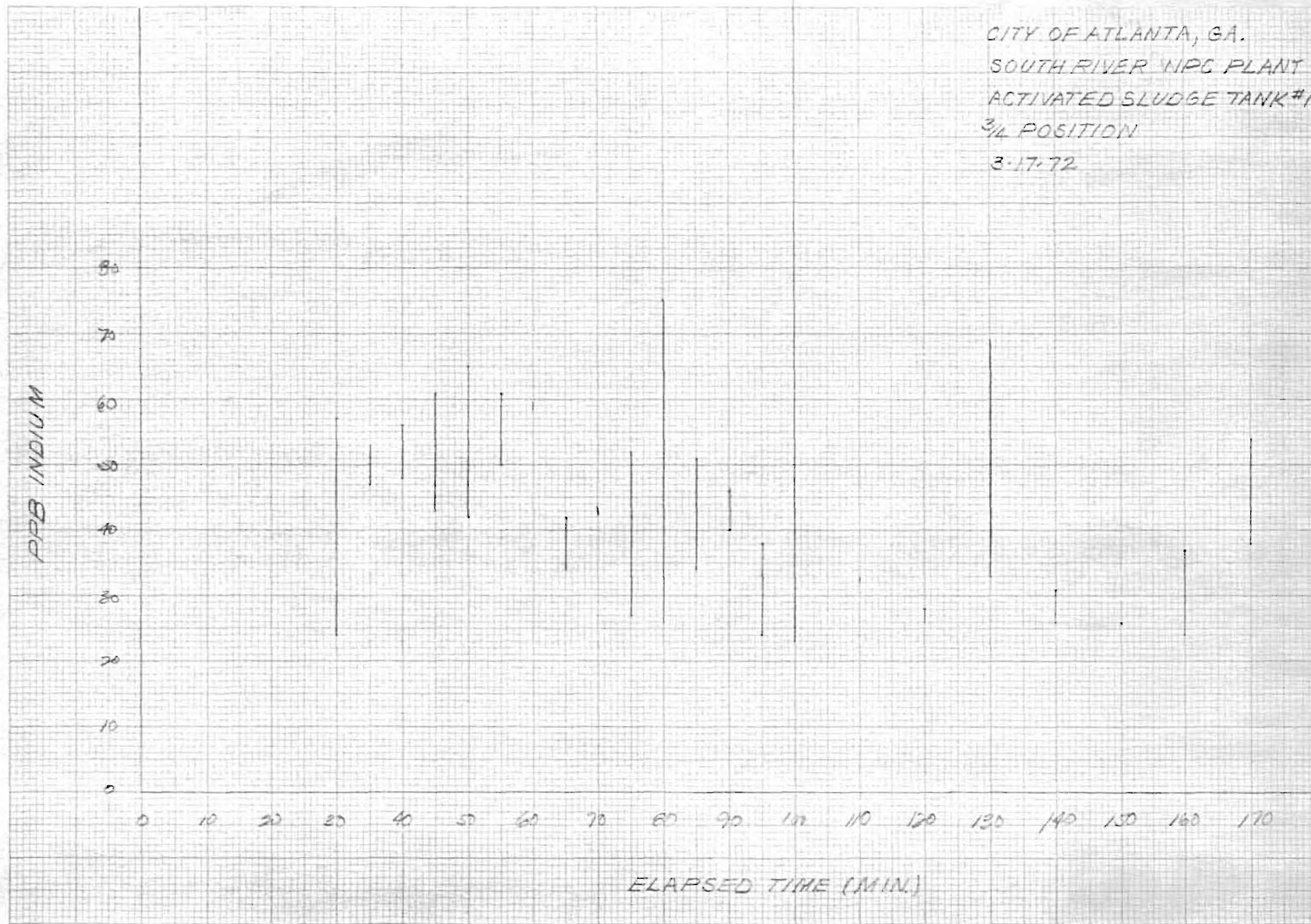
  
T. F. Craft  
Principal Investigator

TFC:lsg  
Attachments

cc: H. L. Baker  
G. W. Leddicotte  
Addressee (3 copies)  
Dr. H. M. Roth, Oak Ridge (3 copies)

351

CITY OF ATLANTA, GA.  
SOUTH RIVER WPC PLANT  
ACTIVATED SLUDGE TANK #1  
3/4 POSITION  
3-17-72





CITY OF ATLANTA, GA.  
SOUTH RIVER WPC PLANT  
ACTIVATED SLUDGE TANK #1  
1/4 POSITION  
3-17-72

PPH INDIUM

100  
90  
80  
70  
60  
50  
40  
30  
20  
10  
0

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170

ELAPSED TIME (MIN.)

PPB IODIUM

100

80

60

40

20

0

10

20

30

40

50

0

10

20

30

40

50

60

70

80

90

100

110

120

130

140

150

160

170

CITY OF ATLANTA, GA.  
SOUTH RIVER WPC PLANT  
ACTIVATED SLUDGE TANK #1  
RETURN SLUDGE  
3-17-72

ELAPSED TIME (MIN.)

LIBRARY DOES NOT HAVE MONTHLY PROGRESS LETTERS #16 and #17.





GEORGIA INSTITUTE OF TECHNOLOGY

EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

July 19, 1972

Mr. Robert L. Butenhoff  
Isotopes Development Branch  
Applied Technology Division  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Eighteenth Monthly Progress Report - June 11-July 10, 1972  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303-001

Dear Mr. Butenhoff:

Another field experiment involving activated sludge has been performed at the South River WPC Plant of the City of Atlanta. The problem of sample contamination has seemingly arisen again. Although utmost care was taken in the collection of samples, indium was found in (or on) each sample vial. As this problem never arose when experiments were performed on sedimentation basins, the situation is puzzling. A different activable isotope will be used in the next experiment, and extreme precautions in sample collecting and handling will be exercised.

The difficulty in following the sewer line across the Northlake shopping center has now been resolved. A detailed map was discovered by the Northlake maintenance department and the numerous storm and sanitary sewer manholes can now be identified. A field experiment is now being planned.

An extended experiment in measuring the active volume of a digester is in progress. Indium was added to the Marsh Creek WPC plant digester and samples taken daily for five days and then at longer intervals. The schedule at present is to collect a sample each week, and this will be continued for several more weeks.


Plans have been made with the Georgia State Department of Natural Resources, formerly the Water Quality Control Board, to participate in their fall Short School. This is a training course that is offered to increase the effectiveness of waste treatment plant operators. This particular session will be held at Douglas, Georgia and is designed for advanced operator training. We will deliver a lecture and discussion of tracer techniques and will put on a demonstration at the Douglas treatment facility. Attendance at these schools is usually in the 40 to 50 range, with many municipalities represented. It is felt that this session will enable us to reach a large number of responsible

Mr. Robert L. Butenhoff  
July 19, 1972


-2-

people and give them enough information to actually try tracer tests in their own plants.

Yours truly,

Geoffrey G. Eichholz   
Project Director

T. F. Craft,  
Principal Investigator

cc: H. L. Baker   
G. W. Leddicotte  
Addressee 3 copies  
J. A. Lenhard 3 copies  
Research & Technical Support Division  
Box E, Oak Ridge, Tenn.

File

# ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

August 21, 1972

Mr. Robert L. Butenhoff  
Isotopes Development Branch  
Applied Technology Division  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Nineteenth Monthly Progress Report - July 11-August 10, 1972  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303-001

Dear Mr. Butenhoff:

Work on the activated sludge return system at the South River WPC plant is continuing. As previously reported, indium contamination seemed to be a major problem at this specific location, but the exact cause was never fully explained. This problem has not arisen in other situations, and it may be that indium is actually present at the low levels indicated by our analyses.

The problem was combatted by a switch to manganese as the activable tracer. It was recognized that manganese is normally present in sewage, and this background level would have to be subtracted. Manganese was attached to sludge by adding to it equivalent amounts of potassium permanganate and manganous sulfate. The manganese dioxide which is formed is adsorbed by the sludge and forms a particulate tracer that promises to be very useful. Two trials with manganese have been made, but neither was completely satisfactory. Without a visual indicator it is difficult to sample frequently enough at the proper time to obtain optimum results. The plant operator stated that sludge being returned to the activated sludge system was out of the aeration tank about 2.5 hours, so our initial sampling sequence was concentrated in the interval of 2.5 hours after the labeled sludge was added. A slight increase in manganese concentration was indicated, but it was suspected that sampling was discontinued too early. A subsequent test involved sampling for four hours, but the slight manganese increase was not observed to decline as was anticipated. We now plan an extended sampling interval ranging over a 10 or 12 hour period to be sure that any changes which occur will be observed. A large quantity of tracer will also be used.

A demonstration of the use of the tracer technique was held at the WPC plant in Macon, Georgia, on August 8. Waste treatment operators were present from four nearby towns: Milledgeville (3), Dublin (2), Forsyth (1), and Warner Robins (1). Six of the Macon people participated including the plant superintendent and the chemist. Snapshots taken at Macon are enclosed with the original of this letter.



Mr. Robert L. Butenhoff  
August 21, 1972  
Page 2

The Macon plant was operating so well at the time of the demonstration that mixing in the sedimentation basins was quite good and without a distinct density current. Under these conditions the color marker was not as bright as was desired, but was visible. It was shown that flow through each of the four basins involved was not uniform (as designed) but that there was a definite difference between them. A detailed discussion of the experiment is to be prepared and will be sent to each participant.

We are continuing to sample weekly the digester at Marsh Creek WPC plant to which indium was added. The erratic fluctuation of the concentration leads to the belief that mixing in this tank is not very uniform, in spite of the operational procedures used. Sampling will be continued as long as useful data can be obtained.

Yours truly,

Geoffrey G. Eichholz,  
Project Director

T. F. Craft,  
Principal Investigator

cc: H. L. Baker  
G. W. Leddicotte ✓  
Addressee 3 copies  
J. A. Lenhard 3 copies  
Research & Technical Support Division  
Box E, Oak Ridge, Tennessee

# ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

September 14, 1972

Mr. Robert L. Butenhoff  
Isotopes Development Branch  
Applied Technology Division  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Twentieth Monthly Progress Report - August 11-September 10, 1972  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303-001

Dear Mr. Butenhoff:

The laboratory work associated with the tracer demonstration held at the Macon, Georgia treatment plant has been completed. Samples of basin effluent collected at the Macon, Ga. treatment plant were analyzed by neutron activation to quantify the results obtained by visual inspection. The analytical results were very much in accord with the expectations. A brief report on the experiment was sent to each of the participants, and a copy is attached along with the covering letter used. It is felt that this effort has been worthwhile, as the participants displayed a considerable degree of interest and enthusiasm.

A similar presentation and demonstration has now been scheduled for the operator training school to be held at Douglas, Ga. in November. A copy of the confirming letter is attached.

All project personnel have been on vacation during the month, and Mr. Tom Enyeart received his Master's Degree in Nuclear Engineering and has departed. Two new student assistants have been selected and hired. They will report for duty by September 18. Several extensive field experiments are planned, and with the additional help now available can be carried out within the next few weeks.

Yours truly,

Geoffrey G. Eichholz,  
Project Director

T. F. Craft,  
Principal Investigator

cc: H. L. Baker  
G. W. Leddicotte  
Addressee 3 copies  
J. A. Lenhard 3 copies  
Research and Technical Support Division  
Box E, Oak Ridge, Tennessee



JOE D. TANNER  
Commissioner

# Department of Natural Resources

ENVIRONMENTAL PROTECTION DIVISION  
47 TRINITY AVENUE, S.W.  
ATLANTA, GEORGIA 30334

R. S. HOWARD, JR.  
Division Director

August 31, 1972

SEP 1 RECD

Dr. T. F. Craft  
Engineering Experiment Station  
Georgia Institute of Technology  
225 North Avenue, N.W.  
Atlanta, Georgia 30309

Re: 1972 Fall Operator Training School

Dear Dr. Craft:

Your proposed presentation and demonstration on tracers for study in wastewater treatment processes will be a great addition to our 1972 fall operator training school. We are scheduling your presentation for 3:00 P.M. on Wednesday, November 15, 1972, at South Georgia College and the demonstration at the Douglas Water Pollution Control Plant at about 4:00 P.M.

You will be participating in the advanced course in wastewater treatment, and we expect about 25 persons to enroll in that course. We appreciate your willingness to participate in this important training function, and we look forward to seeing you at Douglas.

Sincerely yours,

✓ J. C. Meredith, P.E.  
Program Manager  
Training and Grants Service

JCM:rb

cc: City of Douglas



# ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

September 13, 1972

Enclosed is a short description of the demonstration in which you participated on August 8 at the Macon treatment plant. The results show that the basin was operating very efficiently at that time, although flow was not equally divided between the four sections.

Your presence was appreciated and it is hoped that this demonstration will encourage you to use the same technique in your own plant if the need should ever arise.

If I can be of assistance in any way, don't hesitate to call on me.

Yours truly,

T. F. Craft, Ph.D.  
Senior Research Scientist

TFC/mw

August 15, 1972

## Demonstration of Tracer Technique

Macon, Georgia August 8, 1972

The primary sedimentation tank at the Macon wastewater treatment plant is divided into four separate compartments, each fed from a single common channel. No particular difficulty has been encountered with the operation of this process, but the plant operators were aware that flow was not evenly divided among the separate compartments. They had investigated this matter earlier with a dye tracer, some of which passed through the basin in about 25 minutes.

The August 8, 1972 demonstration was held to demonstrate a technique being developed by The Engineering Experiment Station, Georgia Institute of Technology. This work is supported by the U.S. Atomic Energy Commission.

The tracer consisted of 40 grams of the rare element indium which is not found in wastewater. It was dissolved in nitric acid and diluted with water to about one gallon. A pound of bright red dye, Rhodine 6B, dissolved in a gallon of water was also used to visually indicate the presence of the tracer element. These solutions were poured into the plant influent channel where the flow is distributed among the four compartments. On this date the basin was operating very efficiently, and no dye became visible in the effluent for nearly an hour. Samples were collected at frequent intervals, and subsequently analyzed for indium content. The analyses were carried out at Georgia Tech by the neutron activation technique, utilizing the Georgia Tech Research Reactor. Duplicate samples were examined, and the results are shown in Figures 1 and 2. It is apparent that the peak concentration appeared in the effluent of the southwest quadrant at about 70 minutes. The maximum in the southeast sector appeared about 8 minutes later. Less tracer entered the other compartments, and no distinct peak was observed.

From these results it appears that insufficient dye was used to produce the very sharp color change that is most easily recognized. When a basin is operating efficiently more dye is required because the entire contents of the basin must become colored. When a density current is present, only the moving fraction of the volume requires color. As pointed out, it is not mandatory to include any dye with the indium. The color simply indicates the progress of the tracer and reduces the number of samples required.

It is therefore concluded that the four compartments of the basin were operating without appreciable density currents, but flow was not evenly distributed among the four compartments.

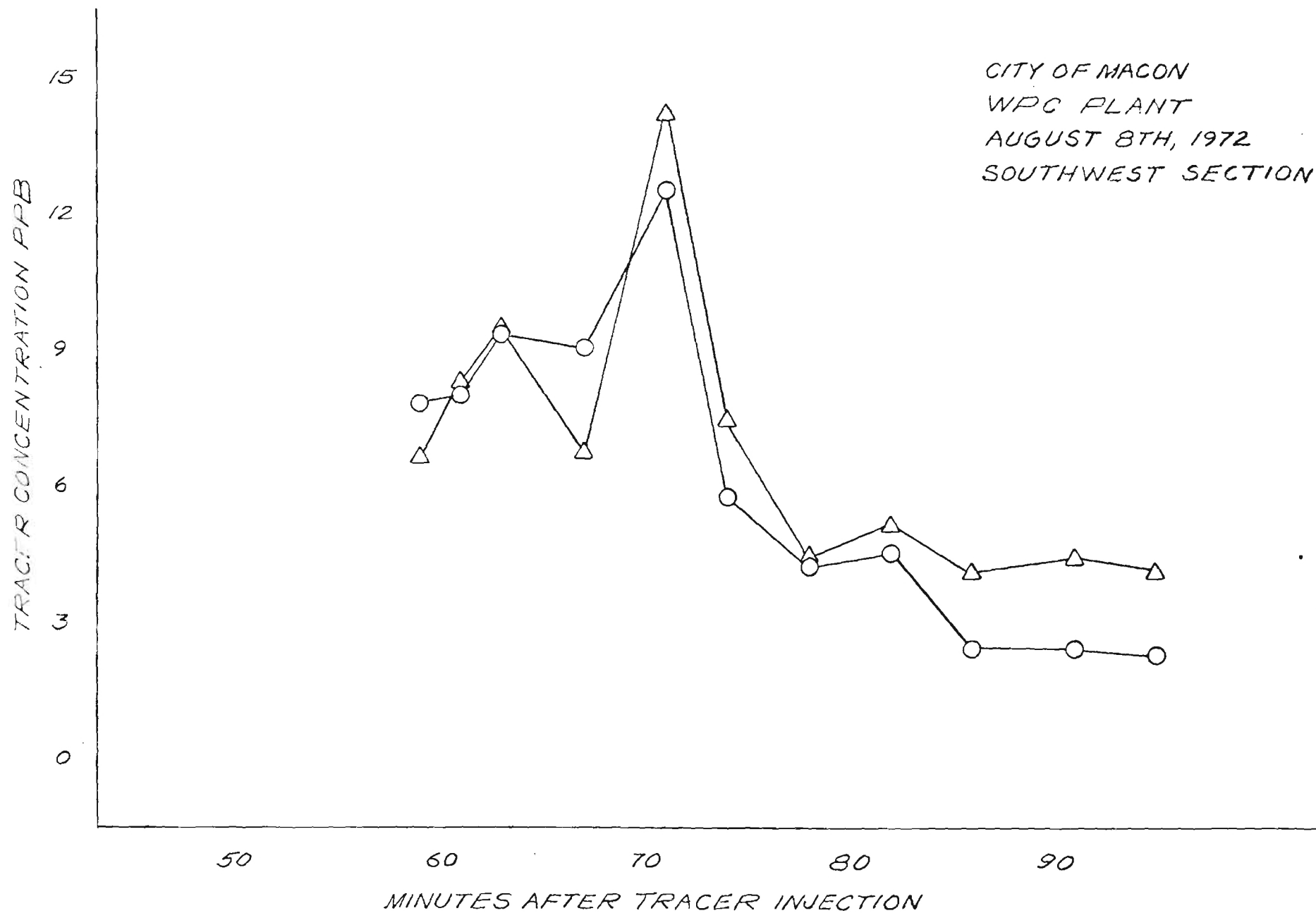


Figure 1. Tracer concentration in primary sedimentation basin, southwest section.



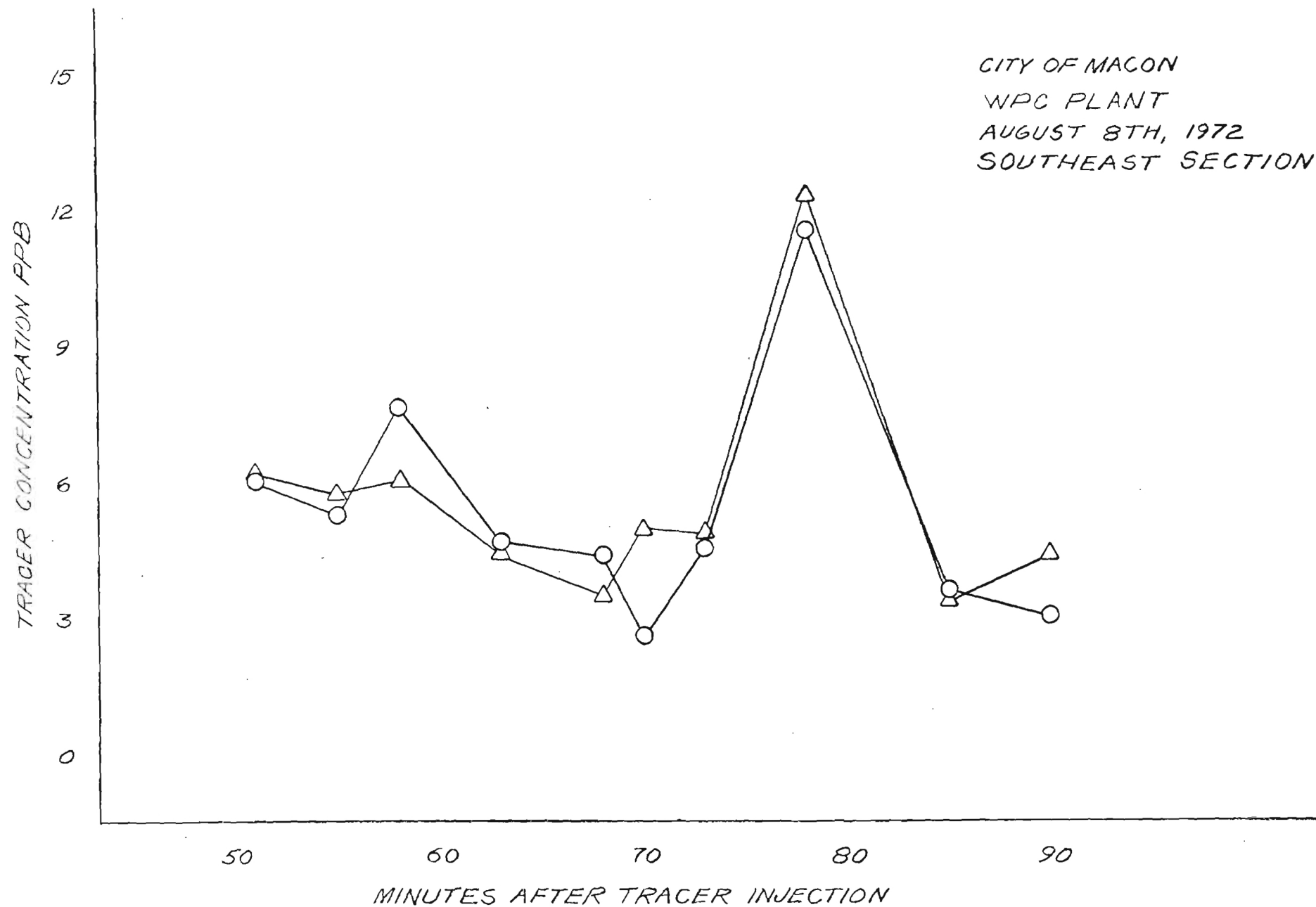


Figure 2. Tracer concentration in primary sedimentation basin, southeast section.

# ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

October 26, 1972

Mr. Robert L. Butenhoff  
Isotopes Development Branch  
Applied Technology Division  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Twenty-First Monthly Progress Report - September 11-October 10, 1972  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303-001

Dear Mr. Butenhoff:

More field experiments have been performed utilizing manganese as the activable tracer. Sludge can be labeled very effectively with manganese by mixing stoichiometric amounts of manganous sulfate solution with potassium permanganate solution in the presence of sludge. The manganese dioxide that is formed adheres strongly to the organic matter and is readily detected in samples collected downstream. The manganese equilibrium between solid and liquid is favorable to the solid, as analyses have shown under normal conditions sludge may contain 9-10 ppm manganese while the supernatant liquid contains about 0.5 ppm. The only disadvantage of manganese occurs in instances where it is already present in the flow to be studied. However, if the "background" level is taken into consideration, reliable results can be achieved.

A field test was carried out at Sandy Creek WPC plant where manganese-labeled sludge was used. Quart samples and 1 ml samples were collected at the effluent end of the sedimentation basin. The quart samples were filtered and the sludge collected on filter paper was activated, giving satisfactory results. The 1 ml samples were activated without any preparation, but the manganese level was found to be indistinguishable from the natural background.

Two experiments have been performed at the new Flint River WPC plant of the City of Atlanta. This small activated sludge plant replaces an old trickling filter plant that was abandoned because of an airport expansion. Manganese-labeled sludge was used in both cases to measure time-of-flow of sludge into and out of the aeration chamber. Results were acceptable, but can be improved by sampling at additional points.

Work has been started on a computer program to handle directly the output of a pulse height analyzer. Our present data handling is reasonably efficient, but an improved procedure would save operator time by reducing manual calculations.

T. F. Craft attended the National Conference of the Water Pollution Control Federation that was held in Atlanta October 8-13. A number of papers of general interest and some pertaining directly to our work were presented.

Yours truly,

T. F. Craft,  
Principal Investigator

TFC/jcb

cc: H. L. Baker  
G. W. Leddicotte  
Addressee 3 copies  
J. A. Lenhard 3 copies  
Research and Technical Support Division  
Box E, Oak Ridge, Tennessee

# ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

November 27, 1972

Mr. Robert L. Butenhoff  
Isotopes Development Branch  
Applied Technology Division  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Twenty-Second Monthly Progress Report - October 11-November 10, 1972  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303-001

Dear Mr. Butenhoff:

For the past several months samples have been collected from the digester at the Marsh Creek STP operated by the City of Atlanta. The attached graph shows the indium content as a function of time. There is considerable range of values in all instances where more than a single sample was collected. The wide fluctuations in indium concentration suggest that mixing in the tank is far less thorough than is commonly supposed. The situation is similar in the digester at Sandy Creek. Samples spanning three weeks have been collected already, and so far no definite trend in concentration has been established. A graph of results to date is attached.

Laboratory work has been performed using lanthanum and scandium as the activable elements. These elements are seemingly less firmly attached to organic sludge than manganese, although the manner of preparation may account for most of the difference.

The computer program under development has been considerably improved, although it is still not in final form. When completed, it should accept directly the results from a pulse height analyzer, examine the spectrum, and determine the various elements present. It may be practical to determine the quantity of each element present, but qualitative analysis is the primary goal at this time.

Yours truly,

T. F. Craft,  
Principal Investigator

TFC/mw

Encl.

cc: H.L. Baker  
G.W. Leddicotte  
Addressee 3 copies  
J.A. Lenhard 3 copies  
Research and Technical Support Division  
Box E, Oak Ridge, Tennessee

*[Handwritten signature]*



# ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

December 22, 1972

Mr. Robert L. Butenhoff  
Isotopes Development Branch  
Applied Technology Division  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Twenty-Third Monthly Progress Report - November 11-December 10, 1972  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303-001

Dear Mr. Butenhoff:

The fall Operators Short School, sponsored by the Georgia Water and Pollution Control Association and the Georgia State Environmental Protection Agency, was held at Douglas, Georgia. T. F. Craft lectured the Advanced Operators session on the use of tracers and tracer methods for the evaluation of plant performance. Twenty-seven operators representing more than twenty different treatment plants attended. A number of questions were raised and discussed.

Following the lecture, a demonstration was held at the Douglas sewage treatment plant. Various members of the group were assigned to specific sampling points to collect the samples at selected intervals. It was felt that active participation would be more meaningful than passive observation, and it is believed that this was the case. A number of favorable remarks were heard, and the entire session was considered very successful.

A tracer experiment was carried out at the Snap Finger treatment plant in DeKalb County. The plant is new and is not yet operating properly. It is planned to compare the data collected with the results of a later experiment to be performed when the plant is functioning according to specifications.

The computer program for spectrum analysis has been improved and a few runs have been made. This program compares unknown peaks to a file of the spectra of various radioisotopes. The utility of the program will be enhanced as the number of spectra in the reference file is increased.

Yours truly,

T. F. Craft,  
Principal Investigator

G. G. Eichholz,  
Project Director

TFC/mw

cc: H. L. Baker ✓  
G. W. Leddicotte  
Addressee 3 copies  
J.A. Lenhard 3 copies  
Research and Technical Support Division  
Box E, Oak Ridge, Tennessee

# ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

January 18, 1971<sup>3</sup>

Mr. Robert L. Butenhoff  
Isotopes Development Branch  
Applied Technology Division  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Twenty-Fourth Monthly Progress Report - December 11-January 10, 1973  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303-001

Dear Mr. Butenhoff:

Laboratory and computer work have been carried out during the month, although working time has been limited due to year-end holidays. Severe weather conditions have prevented any outdoor field tests.


We are continuing the study of trace elements in waste effluents; with a view to possible use of certain common inexpensive elements as tracers. It is difficult to concentrate water samples sufficiently for effective analysis without introducing large possible errors. Evaporation is being used, but this raises the question of contamination from the container in which evaporation takes place. Plastic films have been tried, but their trace element composition is not very favorable. One bag intended for oven baking was found to contain the following: iodine, bromine, aluminum, manganese, copper, chlorine, and sodium. This is a highly undesirable situation, as many of these elements could possibly be present also in the water.

Attempts to use chelating resin for extraction of cations has also been less than satisfactory. Different ions are removed optimally at different pH values, and a single extraction does not appear sufficiently reliable. Work is continuing on this problem.

The computer program is still being revised and improved. A new sub-routine for calculating the centroid of peaks has been developed and may give more precise results than heretofore obtained. A library of reference spectra is being accumulated, so that unknown spectra can be compared readily with the spectra of identified elements.

Yours truly,

T. F. Cratt,  
Principal Investigator

G. G. Eichholz,  
Project Director 

TFC/mw

cc: GTRI ✓  
G.W.Leddicotte  
Addressee 3 copies  
J.A.Lenhard 3 copies  
Research & Technical Support Division  
Box E, Oak Ridge, Tennessee



## ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

February 27, 1973

Mr. Robert L. Butenhoff  
Isotopes Development Branch  
Applied Technology Division  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

Twenty-Fifth Monthly Progress Report - January 11-February 10, 1973  
AEC Contract No. AT-(40-1)-4156  
Our Project No. A-1303-001

Dear Mr. Butenhoff:

A full-scale field evaluation of a settling basin has been carried out at the Flint River Treatment Plant of the City of Atlanta. A severe bulking problem is present at this facility, and the operators and consulting engineers have been trying different procedures to improve conditions. The tracer test was undertaken to determine the behavior of the final settling basin.

At the present rate of flow, it was calculated that the average detention time should be four or five hours. A preliminary test using only dye, revealed a very severe short-circuiting situation as dye appeared in the outlet weir in less than half an hour. Dye and indium tracers were both utilized in the main test. It had been previously observed that bulking solids overflowed primarily from the outer edge of the weir, so samples were collected on both sides of the weir at three different locations.

Following neutron activation analysis of the collected samples, results for each sampling point were plotted and copies are attached. The curves for each pair of points were very similar, but the pattern of all of them is different from what we have observed in other basins. An early peak concentration appears in 30-40 minutes at position C and D, but instead of steadily diminishing, the values drop and then rise again. Points E and F are also characterized by periods of high, then low, then high tracer concentrations. Appearances at A and B are more "normal," but there was an upward trend at the time sampling was ended.

No detailed explanation of these results has been developed, although it appears there is a short-circuiting by some of the flow which reaches the weir very rapidly. The rest of the flow moves in some undefined but different manner, reaching peak concentrations at a much later time.

Mr. Robert L. Butenhoff  
February 27, 1973

-2-

The analysis of water and wastewater for trace elements is continuing. It has been found that two irradiations per sample (30 seconds and 1 hour) are effective for short and long-lived isotopes, and no preliminary concentration of the sample is required.

Yours truly,

T. F. Craft  
Principal Investigator

G. G. Eichholz,  
Project Director

TFC/mw

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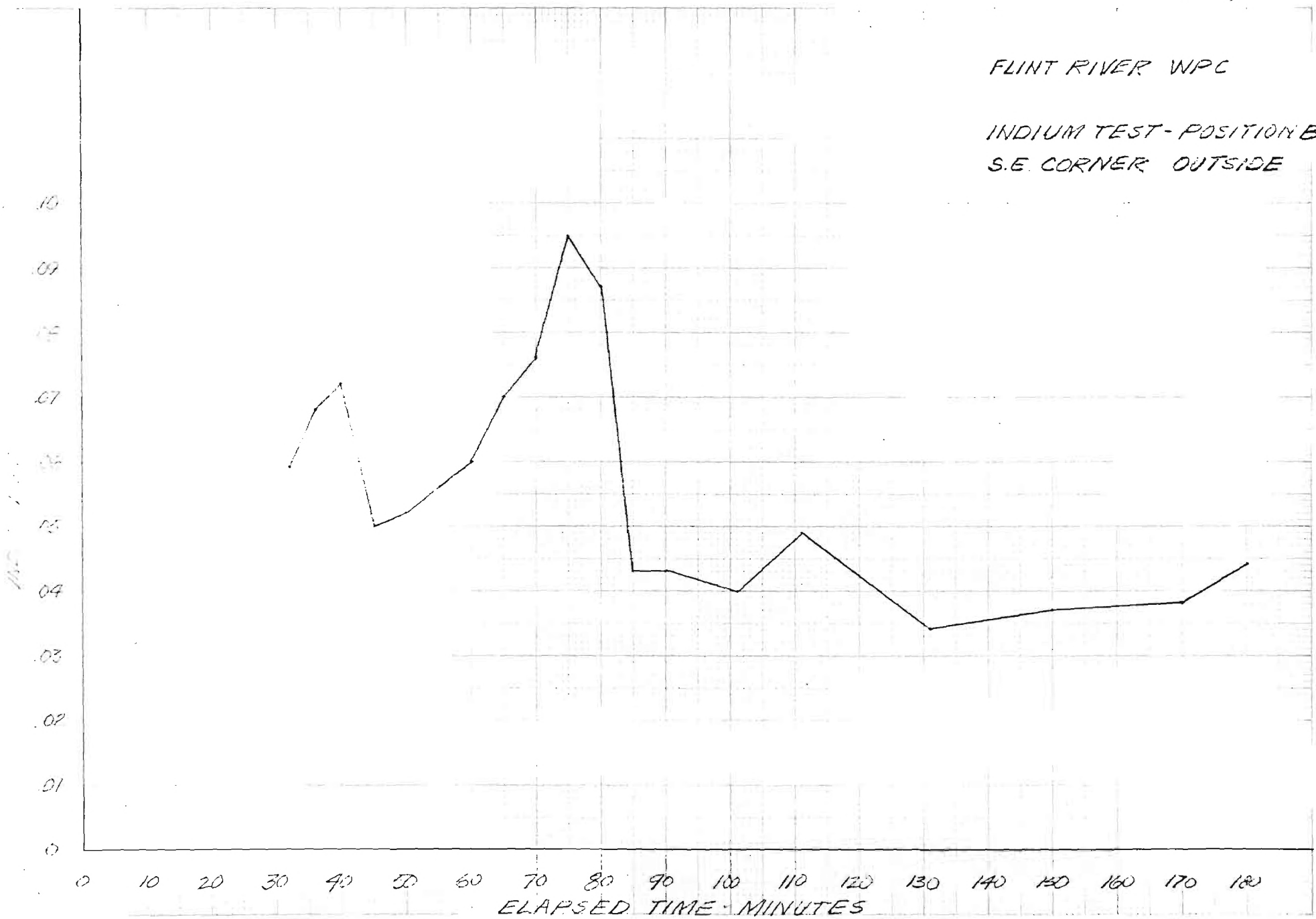


2-5-73



FLINT RIVER WPC

INDIUM TEST - POSITION B  
S.E. CORNER OUTSIDE



FLINT RIVER WPC

INDIUM TEST- POSITION C  
LEFT SIDE OUTSIDE

.07

.06

.05

.04

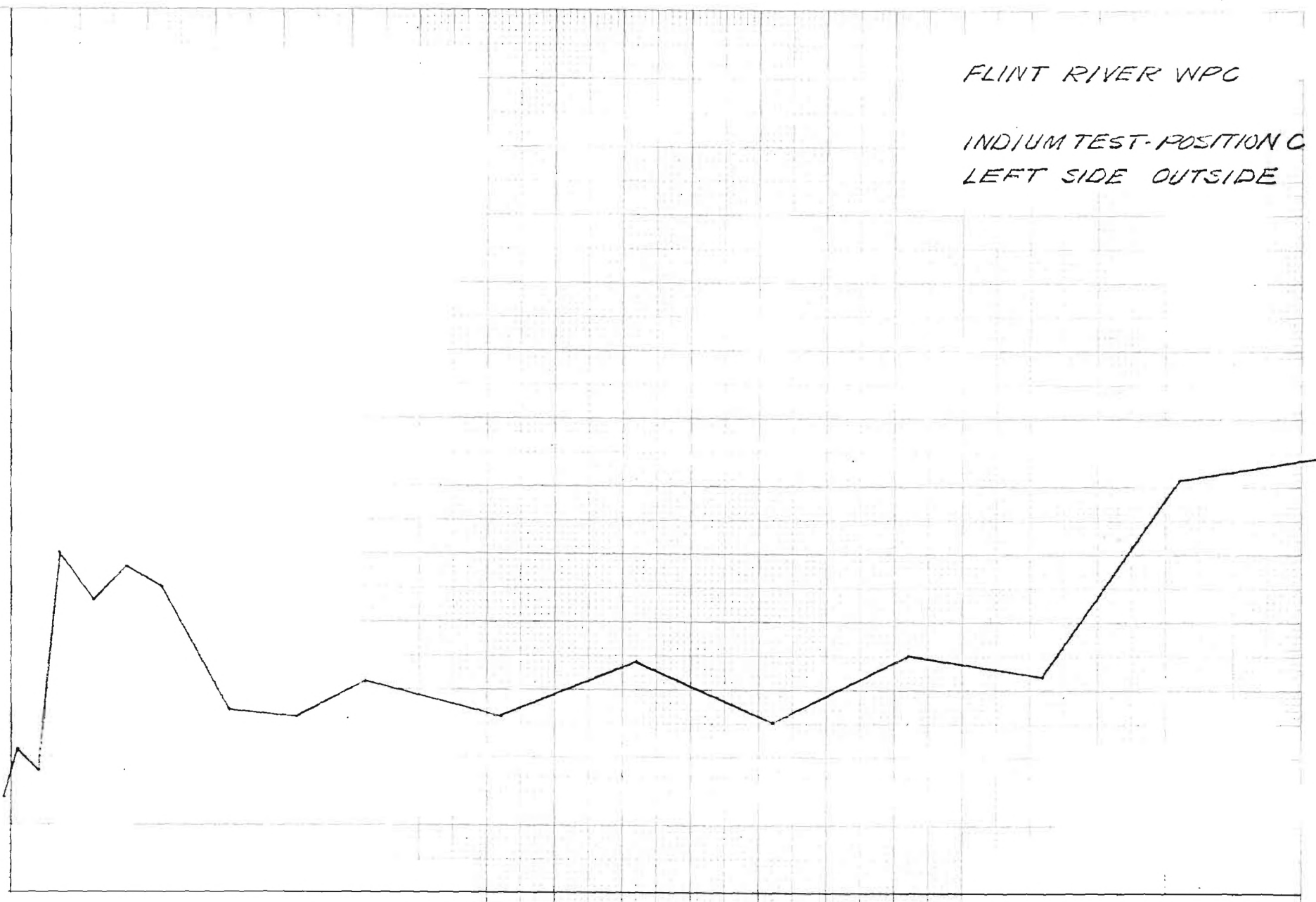
.03

.02

.01

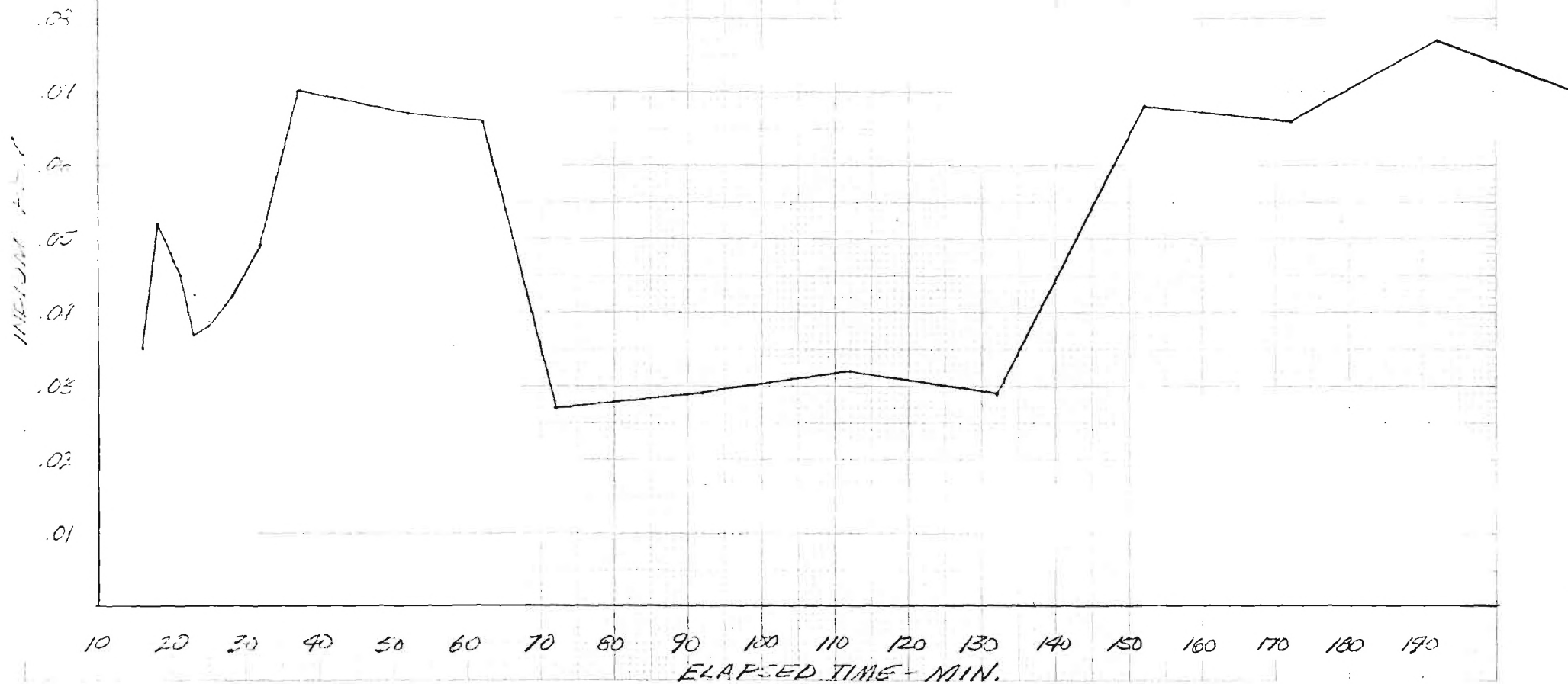
0

20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200  
ELAPSED TIME- MINS.



FLINT RIVER WPC

INDIUM TEST - POSITION E  
RIGHT SIDE INSIDE

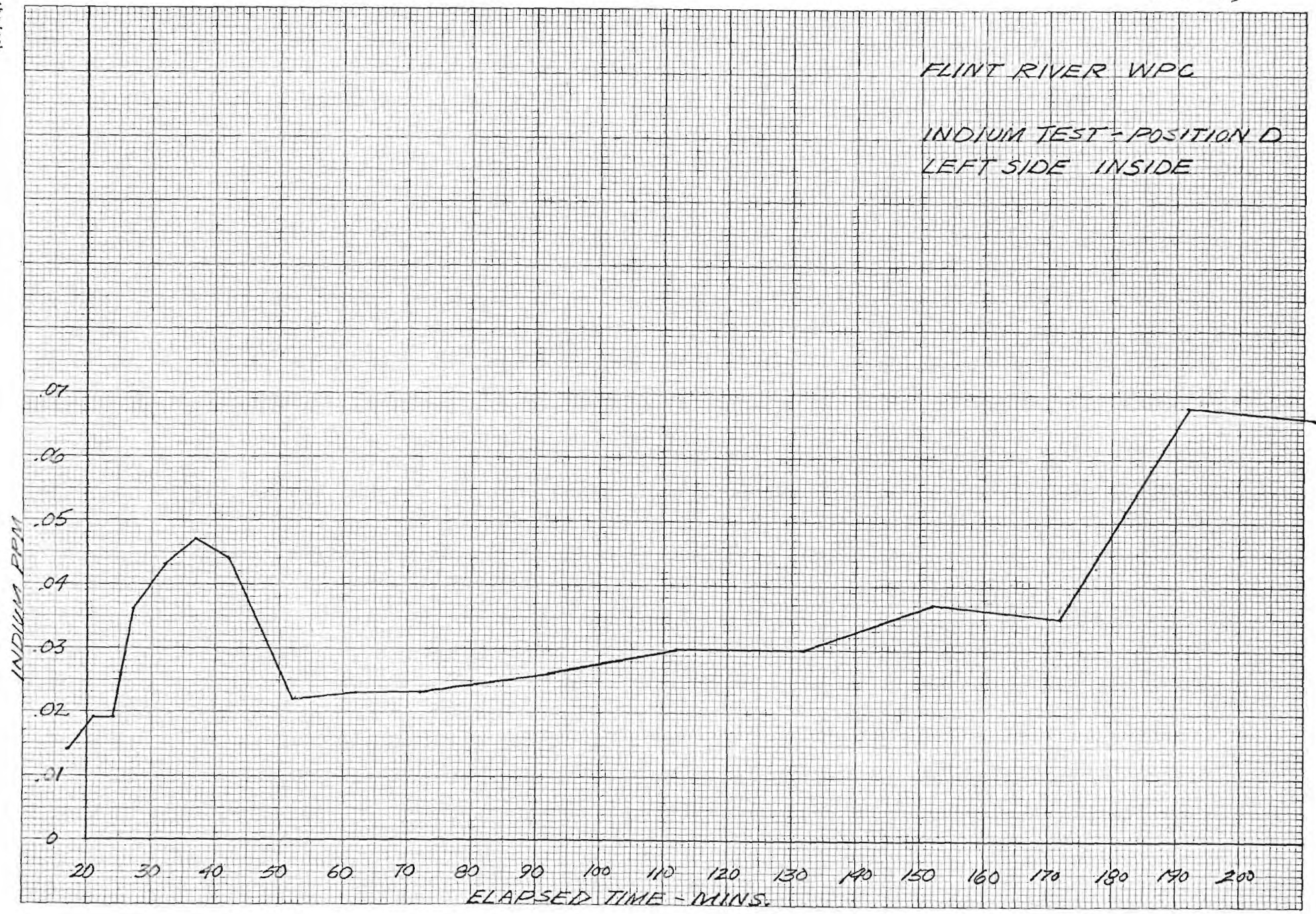




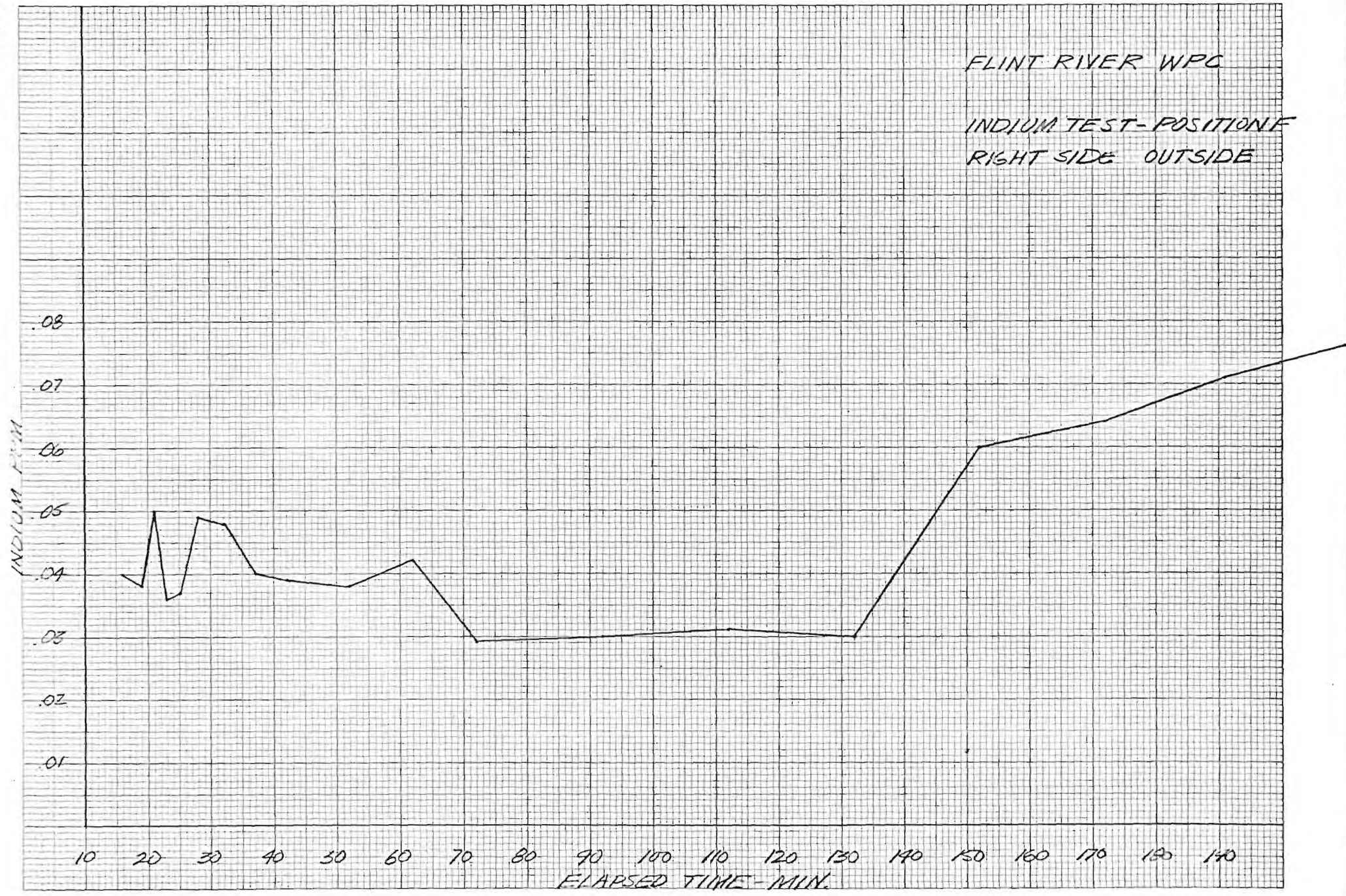
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FLINT RIVER WPC

INDIUM TEST - POSITION D  
LEFT SIDE INSIDE



2-5-73





ORO-4156-1

**EVALUATION OF TREATMENT PLANTS BY TRACER METHODS**

Annual Report, January 15, 1971—January 14, 1972

February 1972

Engineering Experiment Station  
Georgia Institute of Technology  
Atlanta, Georgia

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EVALUATION OF TREATMENT PLANTS BY TRACER METHODS

January 15, 1971 - January 14, 1972

Annual Report

T. F. Craft, G. G. Eichholz, and S. N. Millspaugh

ENGINEERING EXPERIMENT STATION  
Georgia Institute of Technology  
Atlanta, Georgia 30332

Date Submitted: February, 1972

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## ABSTRACT

To overcome the practical difficulties associated with the use of radiotracers or dye markers in evaluating the performance of sewage treatment plants, the use of stable elemental tracers followed by post-sampling neutron activation analysis has been investigated. Of the various possible tracer elements, indium offers the greatest attraction on account of its high neutron capture cross section, its absence from most natural waters, and its low toxicity. Tests have been performed to establish the most convenient procedure for using tracers in soluble form or adsorbed on various particulates in investigations of treatment plant performance.

Field tests have been conducted at several treatment plants in the Atlanta, Georgia region. The performance of sedimentation basins, trickling filters, and activated sludge tanks has been studied and abnormal operating conditions have been demonstrated in some cases. Work is proceeding to explore the potentialities of the method further, to improve the cost of the test work, and to ensure dissemination of test results within the industry.

## INTRODUCTION

The treatment of municipal wastes by sedimentation and biological oxidation processes is the most widely practiced method of waste treatment and our first line of defense against large-scale environmental pollution. The growth of urban populations in recent decades and the steady increase in water usage for industrial and domestic purposes has imposed a heavy burden on existing facilities, many of which are operating well beyond their design capacity a great part of the time. In addition, it is not often easy to determine precisely whether the various component parts of a plant are operating at or near optimum design conditions, and they may be functioning well below their proper level for long periods before this fact becomes evident. It is, therefore, of prime importance to introduce methods of testing and diagnosis to the operating plants that can yield needed data without interfering with system operations and by methods that can be handled by present plant personnel.

Radioactive tracer methods have been investigated in a wide range of hydrological and plant flow applications for many years, and their utility has been well established. Nevertheless, such tracer methods have found few routine industrial applications in the United States, despite the advantages offered by their use. There appear to be several reasons for this non-use. The first is lack of familiarity; in spite of the number of papers written on the subject, these have usually been written by radioisotope specialists for other isotope specialists, and only rarely have they been presented to groups in the trade or industry concerned. The second is technical; the use of tracer and of specialized counting equipment requires a level of expertise

and sophistication beyond the typical plant supervisor. The third is psychological; the use of radioactive materials is still approached with considerable fear and reluctance by the layman. In addition, the red tape involved in obtaining the necessary licenses and permits acts as a deterrent. The last one is environmental; there is a growing reluctance to add, or permit to be added, any radioactive material, however low in amount, to any open stream or unconfined water system. The net effect of these factors is to almost preclude the use of radioactive tracers in any municipal treatment system, except under special conditions and for research purposes.

In order to overcome this problem and to make available to the water pollution control industry the benefits of the tracer method and the large amount of associated work done, most of it under U. S. AEC auspices, alternative approaches have been explored both to make the method more acceptable to the industry and to provide for training and information transfer in this area. This was the primary purpose of the present project. This report constitutes a summary of the work done during the first year.

#### Method of Attack

There are several parameters in the operation of sewage treatment plants that are of significance in assessing the existing plant conditions and operating efficiency. These include the flow rates in various parts of the system, residence times, flow paths, and recirculation paths. All of these parameters are accessible to tracer methods by well-known dye and radiotracer procedures. Difficulties may arise from the presence of suspended matter, the turbidity of the water involved, and, of course, the open-air situation of such plants. Both dye and radioactive tracers have been used in the present investigation for convenience and to provide correlation with previous work; however, the main purpose of the project was to investigate the utility

of stable tracers to make the method more acceptable and accessible to plant operators.

The general approach was to use a trace element not normally found in local water, such as indium, add it in trace amounts to the flow system under study, and determine its appearance in subsequent samples by subjecting them to neutron activation in the Georgia Tech Research Reactor. This approach has the advantage that a small amount of inert solution only is used so that both the injection and sampling can be carried out by unschooled personnel. No pollution of water by radioactive material occurs, and the tracer addition is well below any toxic level. The need to collect and convey a large number of samples to a reactor facility for activation and counting is a drawback but no different from the procedure employed in tritium tracer work widely used in hydrological investigations. Small university and research reactors are found in many locations throughout the country, so that this step need no longer be considered a major obstacle.

Since the initial results to be obtained were essentially qualitative and to be used in the light of the operators' experience with the normal functioning of his own plant, it was important to devise a procedure that was simple to adapt to local conditions. It was necessary to select sites and subsystems that were representative of good practice and conventional design so that the results obtained could be readily compared to other systems and the utility of the approach would be obvious to other operators.

Through the courtesy of the City of Atlanta Water Pollution Control Division and the Clayton County, Georgia, Water Authority, tracer tests have been done at several of their treatments using dye and stable tracers, as well as a radioactive tracer in one case. These tests have shown the existence of normal and abnormal flow patterns, differential residence times,

and in some cases unexpected recirculation patterns. They have indicated the advantages and disadvantages of this approach and will be described in detail below.

Post-sampling activation analysis differs from conventional radioactive tracer work in several respects. Whereas in the case of radioactive tracers in stream studies it is helpful to have comparable inert material present to avoid radiocolloid formation and excessive fractionation, the use of stable tracers requires the choice of a material that is normally completely absent from the water under test. Since the amount of inert tracer used is governed entirely by considerations of expected dilution, detectability, and cost, it is important to select a material that is environmentally acceptable and completely non-toxic in the concentrations expected. Since sewage is not naturally ingested, only effluent concentrations need be considered here. Another important difference compared with radiotracers lies in the choice of the activated isotope. After sampling, the test sample is exposed to neutrons in a reactor and the induced activity is detected and counted. To be readily detected the tracer must have a high thermal neutron cross section and a good specific activity after activation. This implies a fairly short half life, certainly much shorter than would be convenient for tracer field tests. In addition, the gamma rays emitted should be readily discriminated against those from other trace elements normally present in the waste waters, notably sodium, which will be activated at the same time.

An essential part of the project, therefore, has consisted of selecting tracer elements that meet the above criteria and developing methods for injecting them into the systems, as well as for attaching them to suspended solids characteristic of those found in the waste water.



## EXPERIMENTAL DETAILS

In order to evaluate the operation of treatment plants, it was decided to concentrate on the following aspects:

1. Selection of tracers to be used in terms of ease of detection by activation analysis, availability, and acceptable cost
2. Methods of tagging or attachment to suspended solids
3. Background determinations of existing trace elements in waste waters and identification of possible interferences
4. Field tests on portions of treatment plants to evaluate the sensitivity of the tracer and to compare the post-sampling activation analysis procedure with both dye markers and radioactive tracers
5. Interpretation of results in terms of plant operations and information transfer to the pollution control industry, initially in the local region.

### Selection of Tracer Material

In order to be useful as a stable tracer for subsequent detection by neutron activation, an element must possess a number of particular characteristics. Reactor production of a radioisotope in sufficient quantity to be measurable requires that the target isotope be present in sufficient abundance, that it have a reasonably large thermal neutron capture cross section, and that it produce a radioisotope of suitable half life and decay properties. The importance of the chemical properties of the element depends to some extent on the condition of the experiment and on whether or not absorption of the tracer on a substrate is desired. Toxicity and cost must also be considered.

When a particulate is to be labeled, firm attachment of the tracer is sought, whereas in flow measurements, where the tracer is used in dissolved form, minimum absorption or adsorption on any particulates present is desired. Another important factor is the possible prior presence of the same element in the system to be studied. Complete absence would be best, of course, but it would often be possible to subtract out any existing known background as long as it is not excessive. Manganese falls in this category, as it has appropriate nuclear and other properties, but is found in the waters of the Atlanta area almost invariably. Some potentially useful elements are quite expensive and this may limit their use. A number of elements have suitable characteristics and Table I summarizes the nuclear properties of several of those investigated. Indium was selected as the most suitable tracer in most of the work. Scandium, manganese, and bromine have also been used.

To determine the suitability of these materials, both as soluble tracers and as adsorbed tracers on particulates, activation analyses were run on blank water samples and on spiked solutions. The blank samples established the presence or absence of background trace concentrations in local water samples for the element concerned. The spiked samples served to determine the sensitivity of the selected activation procedure for that element, to calibrate the gamma-ray spectrometer, and to indicate any interfering activity peaks from other trace elements.

For tracer tests on particulates, it was also important to find if a suitable labeling procedure could be developed.

Table I. Elements Considered for Tracer Use

Element	Isotope	Abundance (%)	Cross Section (barns)	Radionuclide	Half Life	$\gamma$ Energy (MeV)
Sc	Sc-45	99.99	13	Sc-46	83.9 d	0.889
Cr	Cr-50	4.31	17	Cr-51	27.8 d	0.32
Co	Co-59	99.99	19	Co-60	5.26 y	1.173
Mo	Mo-98	23.75	0.51	Mo-99	66.7 hr	1.33
						0.181
						0.739
						0.778
In	In-115	95.77	1.54	In-116	53.7 m	1.293
Ce	Ce-140	88.48	0.6	Ce-141	32.5 d	0.146
	Ce-142	11.07	1.0	Ce-143	33.7 hr	0.293
Ta	Ta-181	99.99	21.0	Ta-182	115 d	1.221

### Tagging Tests

Laboratory experiments have been performed to evaluate the ease and effectiveness of incorporating a tracer element into organic and inorganic particles. For tracer tests on suspended matter the optimum situation would be to have a batch of particles of chosen size each containing some tracer attached so firmly that it would not be dissolved away or leached out on prolonged exposure to water. The density as well as the size of the labeled particles should be the same as those of the whole groups of particles whose movement is to be traced.

It has been demonstrated previously that the high cation exchange capacity of vermiculite can be utilized in the preparation of radioactive tracer particles (1). Ground vermiculite is slurried with a solution of the tracer cation, dried, calcined, and reground. The desired size fractions are obtained by sieving. Scandium and indium on vermiculite have now been prepared by this method. Other inorganic carriers studied included kaolin, glass frit, and bottle glass.

In the present work, organic particles that have been subjected to labeling procedures include sewage sludge, oatmeal, grits, and wool. The general technique was to stir the organic particulates into a solution containing the desired element. Half of the mixture was boiled while stirring and the remainder was stirred cold. Wool was not treated by this technique, but was mordant dyed, using the desired cation as the mordant. Effectiveness of the labeling procedure was evaluated by activation analysis of the particulate matter, the decantate, and several successive wash waters. Details of representative experiments and results follow.

### Vermiculite

Ten grams of vermiculite ground to pass a 100 mesh screen were

slurried for several hours in water containing 20 mg of indium sulfate. After standing overnight, the liquid was decanted and the solid residue transferred to a quartz dish. It was dried under a heat lamp and then heated to 2050°F in a muffle furnace. After cooling, the sintered mass was ground in a ball mill. Neutron activation analysis of water in which the ground solid was soaked for several hours showed a count rate of zero compared to 44,000 for solid irradiated simultaneously, confirming the high stability of tracer attachment. This procedure has also been used with scandium as the labeling element and with kaolin as the substrate. All give similar results. The high resistance to leaching is believed due to diffusion of the tracer into the particles and also a surface melting of the particles sealing off the active exchange sites. Previous work in this laboratory (2) has shown that in vermiculite treated in this manner the tracer concentration is independent of particle size, indicating that the attachment of tracer ions is not merely a function of surface area.

#### Glass

Tracer elements stirred into molten glass yield particles that are very resistant to leaching. The procedure consisted of melting about 200 grams of bottle glass or glass frit (Pemco brand) in a pot furnace. Bottle glass melted in the range of 1000-2000°F. The tracer element in dry form (indium sulfate, molybdenum trioxide, scandium oxide) was then stirred into the melted glass. After allowing the melt to soak for a while, it was poured into cold water. The resulting strands and particles of glass were then ground in a ball mill.

#### Organic Substrates

Sewage sludge, oatmeal, and grits have all been subjected to a similar labeling process. A typical procedure was to prepare instant oatmeal



by mixing it with hot water. It was then cooled, a solution of the tracer element added, and the mixture stirred. It was then divided into two portions--one of which was stirred while heating, the other stirred cold. After half an hour the solids were allowed to settle until a reasonably clear sample of the water could be obtained. The solid was then washed with several portions of water, each time separating the solids by settling. Samples of the solid, the initial decantate, and the wash waters were then analyzed for tracer content.

The results were not very precise due to the variable moisture content of the sludge, but they gave the relative distribution of the tracer between the solution and the sludge in the form it would be utilized. The results of several experiments are summarized in Table II for various materials. There appears to be no clear-cut advantage in boiling the mixture. Grits seem to be an unsatisfactory medium for this purpose.

Table II. Ratio of Solids/Decantate Indium Concentrations in Labeling Experiments

Substrate	Unboiled	Boiled
Sewage Sludge	3.8	1.54
Oatmeal	1.64	2.02
Oatmeal	1.45	0.81
Grits	1.90	0.80
Grits	0.32	0.92
Grits (cobalt tracer)	0.36	0.69

## Neutron Activation Analysis

Samples to be analyzed were placed in polyethylene vials, heat sealed to prevent leakage, and then placed in a plastic "rabbit" for insertion into the Georgia Tech Research Reactor via a pneumatic tube facility. The rabbit will hold six of the small irradiation vials, so five samples plus a standard were loaded for each irradiation. Standards were prepared from high purity reagents, carefully weighed, dissolved, and brought to exact volume in a volumetric flask.

While the reactor flux is essentially constant, some fluctuation occurs and maximum precision is ensured most easily by including a standard in each irradiation. This also eliminates the effect of possible errors in positioning or in timing, a matter of major importance with isotopes of short half-life.

The flux in the reactor pneumatic tube system is about  $1.2 \times 10^{13}$  neutrons/cm<sup>2</sup>/sec, and the irradiation time for each group of samples was adjusted to provide a suitable count rate for the concentration of the particular element under consideration. In the case of indium, the most frequently used tracer, an irradiation period of one to five minutes produced sufficient activity for satisfactory results with counting intervals of 100 or 200 seconds (live time).

Samples were counted on a 60 cc lithium-drifted germanium detector used in conjunction with a 1024 channel Nuclear Data Pulse Height Analyzer, Model 2200. The system was interfaced with a Hewlett-Packard Model 9100B Computer that was programmed to calculate the net number of counts in any selected  $\gamma$ -photopeak area (3). This array of equipment served particularly well for the handling of the dozens of samples associated with each field experiment. For best efficiency, two workers were required--one to handle irradiations

and carry samples to the counting area and the other to operate the counting system and record data.

#### Sampling Procedure

For the field tests at sewage treatment plants, liquid samples were collected from tanks, channels, and other locations by dipping with a can attached to a stick of suitable length. Plastic tape was used to secure the stick to the lower side of the can so that it was self supporting when placed on a flat surface. The cost of these samplers was so trivial that they were intended to be disposable, but because of their durability and convenience, they have been used repeatedly and should be satisfactory indefinitely. The self supporting feature is important because, after a sample is collected, portions must then be transferred to irradiation vials, a procedure requiring two hands. The polyethylene vials have a capacity of slightly more than one milliliter and they were supported in wooden blocks containing holes into which they fit snugly. Both the holes, the vials, and the blocks were marked for positive identification. Liquid was transferred from the sampling container to the vials by a one milliliter disposable pipette attached to a 10 milliliter syringe.

During a run, the sampler was rinsed in the liquid to be sampled a few seconds before the moment of collection. After the sample was obtained, the pipette was then rinsed with one or two portions of the sample, and the desired samples pipetted into the vials. The sample was stirred with the pipette if any rapidly-settling solids were observed. Duplicate or triplicate samples were collected, and the vials closed with their attached lids. They were then ready for transportation to the laboratory for analysis.

When the solids content of a flow was to be considered separately from the liquid, larger samples were required. Pint milk bottles were used and

were filled by dipping by hand at the desired location. Cardboard stoppers for these bottles were not available, so squares of aluminum foil were used as closures. The bottles were conveniently transported in milk bottle crates.

In the laboratory these samples were filtered by suction in a Buchner funnel. After all the liquid had passed through, the filter paper was folded and forced into an irradiation vial. Portions of the supernatant were pipetted into other vials for separate analysis.

## FIELD TEST WORK

The laboratory work aimed to developing procedures for detecting the stable tracers by activation analysis and for testing labeling methods for particulates proceeded more or less in parallel with the field tests. These tests were conducted with several purposes in mind; to develop the most convenient methods of injecting and sampling the stable tracer solution; to illustrate the utility of this approach for a variety of real problems that will occur in typical treatment plants on a full-size scale; to compare the stable tracer method with the better-known radioactive tracer method and dye marker method under comparable conditions; and to expose and "indoctrinate" plant operating personnel to such test work.

The following sections describe the various plant tests performed.

### Sites of Field Work

#### Sandy Creek

Much of the field work was carried out at the Sandy Creek Water Pollution Control Plant of the City of Atlanta. This facility was chosen because it is one of the smallest of the municipal plants in the area and is reasonably close to Georgia Tech. It is located off Carroll Drive in Southwest Atlanta and is a one million gallon per day (MGD) primary treatment plant serving a small section of Metropolitan Atlanta between Bankhead Highway and Gordon Road. This plant is a small compact basic unit consisting of screen and grit facilities, two 52' x 12' primary settling tanks, one 40' diameter sludge digester, three sludge drying beds, and basic administrative facilities. Figure 1 is a flow sheet of this plant.

This plant is operating at present under less than ideal circumstances



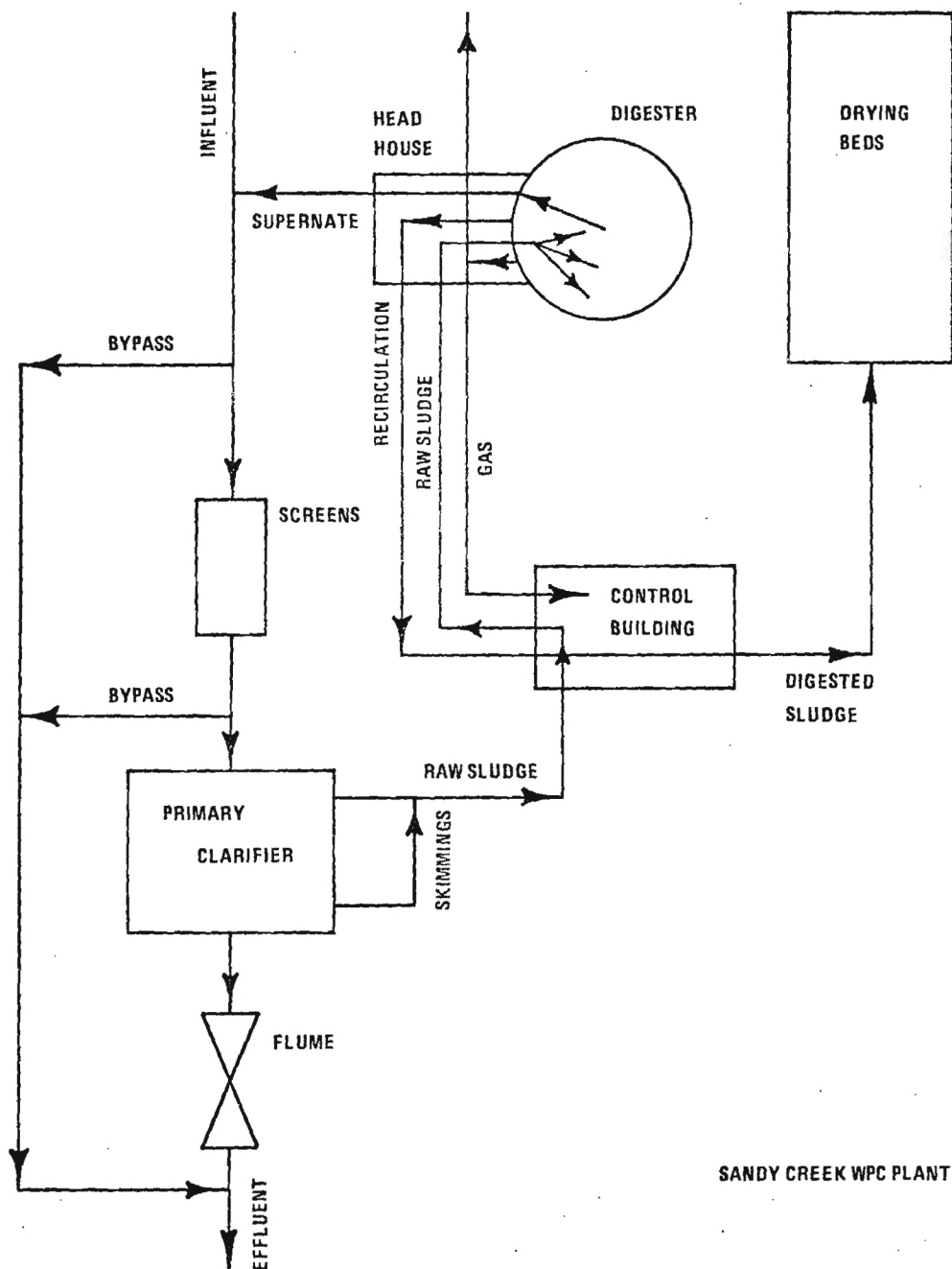


Figure 1. Flow Diagram of Sandy Creek WPC Plant

as it is overloaded to approximately twice its rated capacity as a result of high density housing conditions that have developed in the area. While this situation is very undesirable from the standpoint of the plant operator, it afforded an opportunity to study operations under difficult conditions.

#### Flint River--Clayton County

The Flint River Sewage Treatment Plant of the Clayton County Water Authority is located about 15 miles south of Atlanta, just southwest of Jonesboro, Georgia. It is a 3 MGD standard rate trickling filter plant and consists of four primary and two secondary clarifiers, a 136' diameter trickling filter, two digesters, sludge drying beds, chlorination facilities, and an administration and laboratory building.

Due to growth in the area served by this plant, the present sewage flow is about 4 1/2 MGD, an overload of 50% of the design capacity. Until an expansion of the present facilities can be completed, this overload situation will continue. Attention was directed to this plant because of difficulties that were being encountered in the operation of the trickling filter.

#### Flint River--Atlanta

The Flint River Water Pollution Control Plant of the City of Atlanta is located at the Atlanta Airport near Interstate 285 in northeast Clayton County. It is a 2 MGD standard rate trickling filter secondary treatment plant consisting of the following equipment: two 68' x 20' rectangular primary clarifiers, two 136' diameter standard rate trickling filters, two 68' x 20' final settling tanks, two 45' diameter sludge digesters, six sludge drying beds, basic chlorination facilities, and administrative accommodations.

The site of this plant is needed for airport expansion, and a new plant is under construction nearby. The trickling filters in this plant operate in good, normal fashion and were studied to provide base data for comparison with trickling filters elsewhere that were not functioning properly.

#### South River

The South River Water Pollution Control Plant of the City of Atlanta is located on Jonesboro Road in southeast Atlanta. It is a modified activated sludge secondary treatment plant made up of two basic treatment phases and one sludge treatment phase. The basic units are a 12 MGD modified activated sludge process and a 6 MGD standard rate trickling filter process. These units operate in parallel to give a total plant capacity of 18 MGD.

Although this plant is quite large for preliminary studies, it is the only activated sludge plant located within a reasonable distance. Only one experiment has been performed at this plant so far, but additional work is planned.

#### Measurement of Flow Time in Sewer--Sandy Creek

The initial field test was a measurement of the time of flow through a sewer into the Sandy Creek Plant. In many instances, flow measurements can be easily made by visual observation of a dye marker, but this technique does not readily give quantitative information, and is not applicable to highly colored wastes or to turbid streams that obscure the added color. For convenience and purposes of comparison, a rhodamine dye was added to the stream at the same time as the stable tracer in this test. The flow which we measured was domestic sewage and did not interfere with the added dye marker.

In consultation with the plant superintendent, a manhole was selected for introduction of the tracer solution. Measurements taken from a cadastral

map showed the distance to be about 6400 feet and the superintendent estimated time of flow from the manhole to the treatment plant at about 20-30 minutes.

At 2:19 pm, a gallon of solution containing 600 grams of sodium bromide and 200 ml of Rhodamine WT was introduced into the system at the selected point. Five minutes later a gallon of water containing 450 grams of Rhodine 6B was introduced. Rhodamine WT is a fluorescent dye and reportedly can be detected by a sensitive fluorometer at the parts per billion level. It was expected that this material would not be visible to the eye, but would be detected by a fluorometer so that sampling could be started. Rhodine 6B was added to evaluate its use as a visual indicator. A continuous flow recording fluorometer was therefore positioned at the grit chamber, and sewage was pumped through the fluorometer by a small submersible pump.

At 3:08 pm the fluorometer indicated the arrival of a fluorescent material and the previously initiated sampling interval was reduced from five minutes to one minute. Sampling was continued until 3:30 at which time the fluorometer readings had returned to their background level.

The highly visible Rhodine 6B did not appear until 3:37 pm; 29 minutes after the first tracer, although there was only a five minute interval between the introduction of the two tracers. The flow of sewage during the entire period of the experiment was reasonably constant, and there is no obvious explanation for the longer time required for the second material to travel the same distance as the first.

One ml portions of the samples were pipetted into numbered irradiation vials and returned to the laboratory for analysis by neutron activation. The sample vials were heat sealed, irradiated in the Georgia Tech Research Reactor for 5 minutes, and counted about 2 hours later. Bromine was detected

at levels up to 0.6 ppm in nine of 22 samples collected. These erratic results were due to the low peak-to-background ratio resulting from the presence of only small amounts of bromine. Longer irradiation periods would have improved the counting statistics, but for reasonably accurate results at practical irradiation times, the bromine content should be increased by an order of magnitude. It was therefore considered that other tracers would be preferable for such uses.

The fluorometer is a very sensitive instrument and under ideal conditions would be capable of giving precise results. However, under the field conditions encountered, it proved unsatisfactory. The instrument itself is heavy and requires two men to handle it. It operates on alternating current and requires the use of a portable generator at points where electricity is not available. The bits of paper, rags, and other solid matter in the sewage effectively clogged the intake of the submersible pump so that it was necessary to stop and clean it every 2 or 3 minutes. Only invalid data could be obtained while the pump was not operating. A more fundamental difficulty was the instability of the instrument. Background readings drifted over a range of 2-3% of the scale and created serious doubt as to the precision of the readings at any given time. Because of the inconvenience of this method of tracer detection its use was discontinued and Rhodine 6B was used as a visible marker in all subsequent tests.

#### Activated Sludge

An experiment intended to reveal information on flow conditions in an activated sludge tank was carried out at the South River WPC Plant. At the time of the study, the rate of flow through the tank into which the tracer was injected was approximately 5 MGD which included 1 MGD of return sludge.



The placement of the air diffusers in this tank produces a rolling motion in the liquid, and a given particle presumably moves in a spiral fashion from the inlet to the outlet of the tank. The theoretical detention time is about 2 1/2 hours and the suspended solids in this system average about 2300 mg/l. The tracer solution contained 25 grams of indium as well as 400 grams of Rhodine 6B to serve as a visual indicator. After the tracer solution was poured into the tank, the dye marker was rapidly obscured, and only a slight tinge of color remained after two minutes.

It had been anticipated that visual marking would require rather large amounts of dye, but following this experience it is believed that as much as 20 pounds would be needed to assure continued visibility throughout the tank. Due to the lengthy detention time and the lack of any visual indication as to the location of the tracer front, samples were collected at locations one fourth and one half the length of the tank from the inlet.

It was thought that the vigorous motion of the tank contents would produce a large amount of mixing and concomitantly a high dilution of the added tracer. Referring to Figure 2, it will be seen that longitudinal mixing occurred so that the initial concentration of 63 ppb decreased for 35 minutes at which time a very high peak (130 ppb) appeared. The indium level decreased gradually thereafter with a small, presumably insignificant, fluctuation near the two hour time. At the half way station, a similar pattern was noted. The maximum concentration there was only 70 ppb and occurred 15 minutes after the maximum at the quarter location.

Two vials were filled from the sampler at each time interval, and agreement between the two portions was less satisfactory than for other experiments. The lack of consistency may have been due to variations caused by

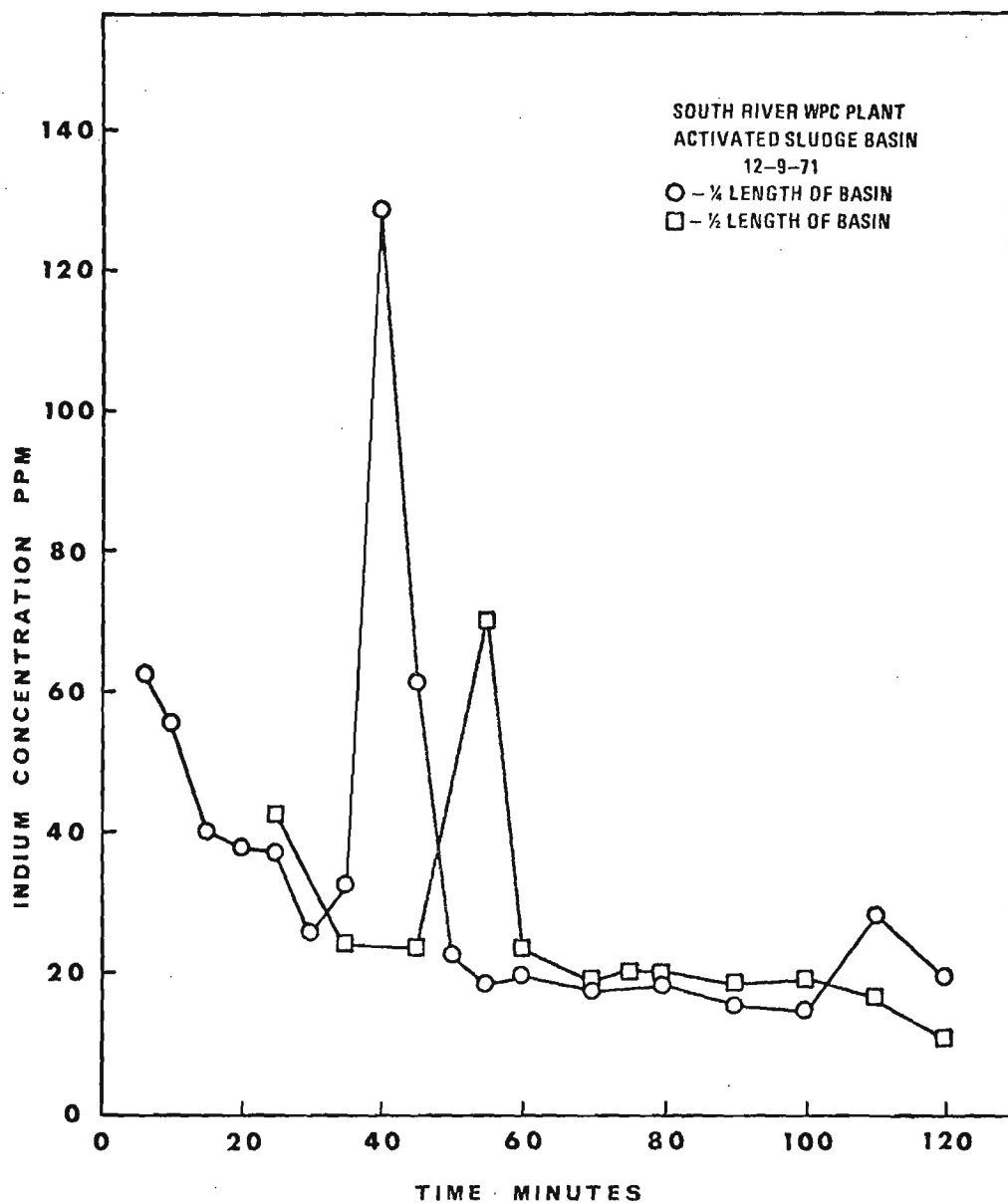


Figure 2. Tracer Concentration at Two Points in South River WPC Plant Activated Sludge Basin

the rapidly-settling solids present. It is believed that most of the tracer was absorbed by the solids present, and any difference in the amount of solids transferred to duplicate vials would cause large differences in the observed results.

Further work is needed to help understand the conditions present in this type of situation and more experiments are planned. A larger quantity of indium will be used, and samples will be taken at three locations along the tank and also at the exit. Without any visual indicator, it will be necessary to estimate the actual time of passage through the tank and to collect samples over the period of time deemed appropriate.

#### Trickling Filter Studies

The Flint River Sewage Treatment Plant of the Clayton County Water Authority had been having difficulty for some time with their trickling filter. Ponding was evident, but more importantly, the BOD reduction across this filter was essentially zero. Gas production of both digesters was far below normal levels and a common cause of these difficulties was suspected. A consulting engineer was called in to assist in solving the problems.

Permission was readily obtained from those in charge for tracer studies to be carried out at any points desired within the plant. This provided an opportunity for comparison of the flow pattern through a badly clogged filter with the normal pattern to be obtained at a later date after the filter had been restored to normal operation.

The initial test was carried out on June 1, 1971, at which time severe ponding was evident. It was observed that the ponded fluid seemed to drain into a few specific crevices rather than to spread evenly and quickly into all the openings between the stones which compose the filter. From this it

was concluded that flow was occurring through a few channels and no appreciable amount of liquid was reaching a major part of the filter. On digging into the filter, it was found that most of the interstices of the stones were filled with a dense gelatinous mass, later shown to be primarily aluminum oxide-hydroxide. The aluminum came from an upstream industrial plant and in time resulted in the plugged filter. With most of the filter plugged and the balance continuously flooded, no bacterial action resulting in appreciable BOD reduction could occur.

The tracer tests were carried out using indium as the activable material plus Rhodine 6B for visual observation. The tracer solution was poured into the dosing box of the filter and samples were collected at the filter outlet and at the center (inlet) and rim (outlet) of both secondary clarifiers. The results of the first test are shown in Fig. 3. The curve labeled "A" represents the concentration of tracer at the filter outlet, which is about eight feet below grade level. The flow at this point was apparently not very well mixed as the dye tracer was more concentrated at the center of the stream of effluent. More thorough mixing occurs in the downstream pipes which divide and deliver the liquid to the center of the secondary clarifiers. If the flow were completely mixed, the maximum concentration would be the same at the filter outlet and the clarifier inlets.

Two samples were lost due to a faulty pipette and experimental points between 5 and 10 minutes for curve "C" are missing. Judging from the slopes produced by the other points, the maximum point for curve "C" would have been comparable to that of curve "B". This supposition is supported by the results of the later test. The maximum in curve "C" occurred after the maximum in curve "B", because the pipe which supplies sampling point C is longer than that supply point B.

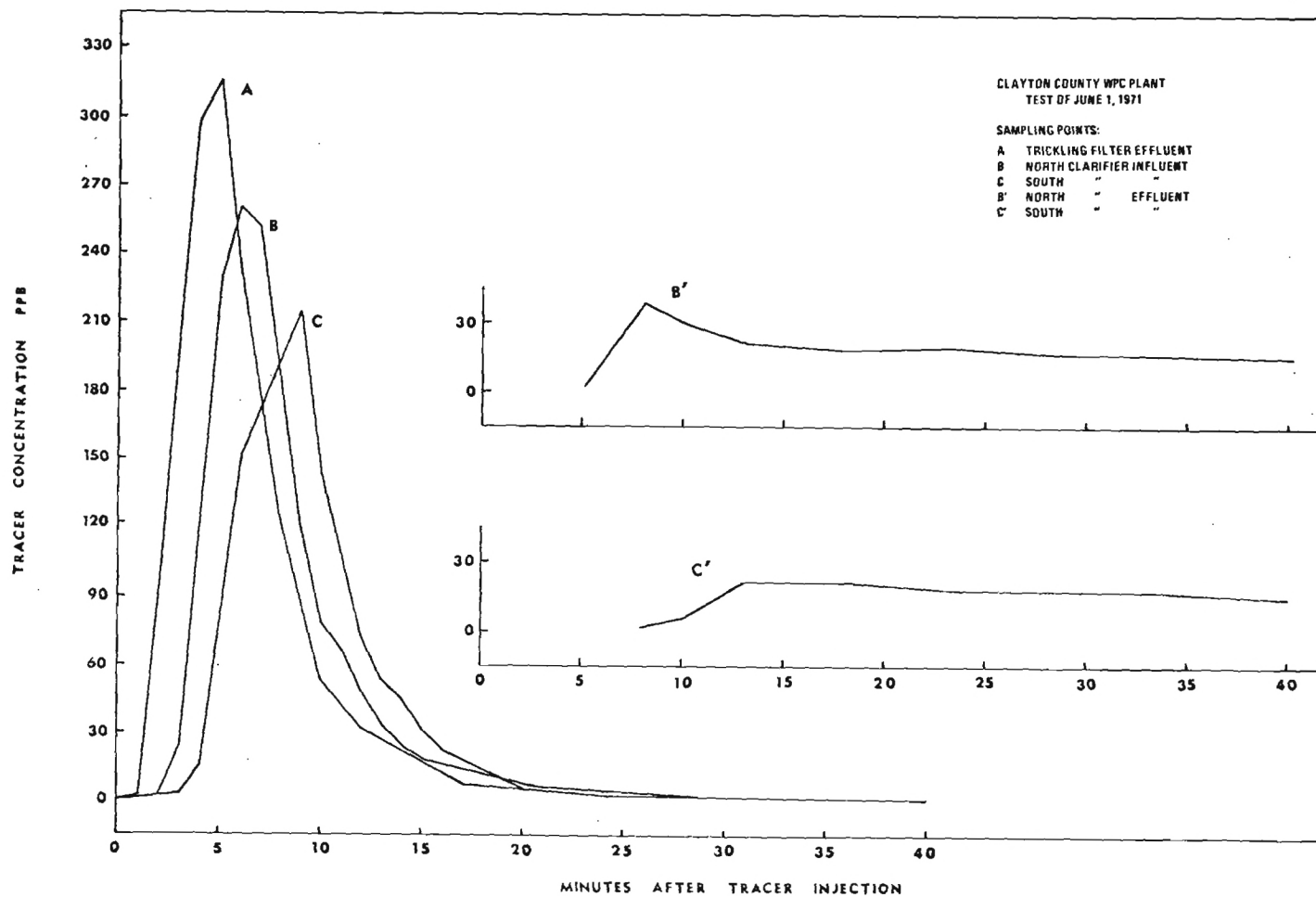


Figure 3. Tracer Concentration at Various Points in the Clayton County WPC Plant, June 1, 1971



The north clarifier has a diameter of 36' and showed a tracer peak at the outlet at about 8 minutes. This very rapid traversal of a basin that should have a much greater detention time is due in part to a faulty arrangement of the basin inlet. The inlet has a metal baffle around it, apparently intended to prevent rapid movement across the surface. The upper edge of this baffle was submerged, however, due to the higher elevation of the outlet (rim) weir. As soon as dye became visible in this tank, streaks of color moved promptly to the outlet. The indium levels were in accord with the observed color and decreased as time went by and better mixing occurred. Because of the mixing, a very long time would be required to dilute the tracer to below the detection level.

The south clarifier has a 52' diameter, and the inlet baffle is above the surface of the water. The tracer concentration at the outlet, therefore, did not peak sharply, but rose to a maximum and decreased very slowly during the remainder of the experiment.

Following this test the consulting engineers had the filter washed with several thousand gallons of 50% caustic soda solution, a treatment which only partially removed the accumulated solid matter. The filter stone was then removed, washed with fire hoses, and replaced. The engineering details of the cleaning and other operational aspects of this problem are to be published by the consulting engineer (4).

After the cleaning of the filter was complete, a period of several weeks was required for the reestablishment of normal biological conditions. On August 24, 1971 a second tracer experiment was performed using the same injection and sampling points as before. The results of the analysis of the collected samples are shown in Fig. 4. In this case the maximum concentrations at points A, B, and C were all about the same, which indicates that

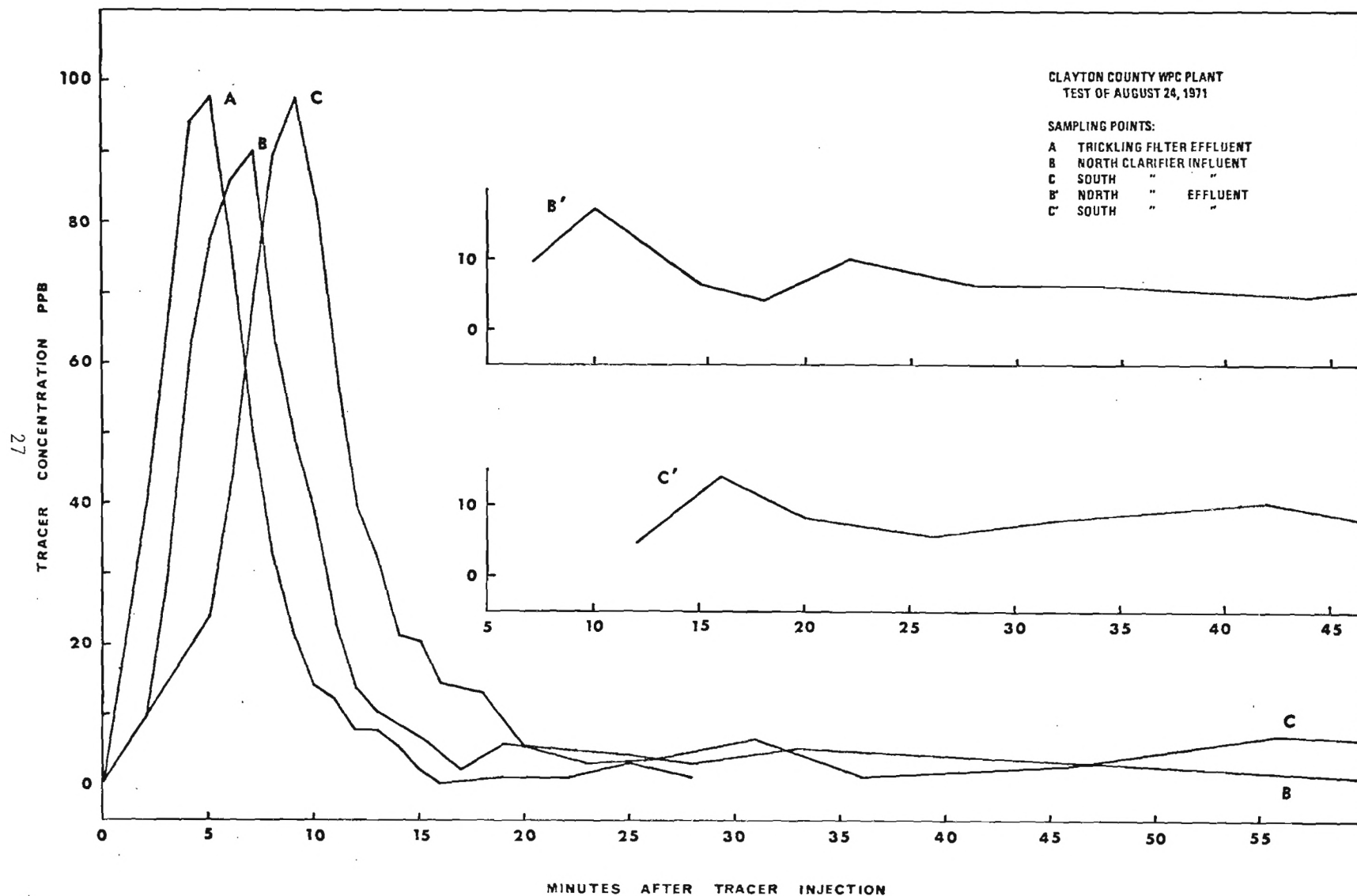


Figure 4. Tracer Concentration at Various Points in the Clayton County WPC Plant, August 24, 1971

perhaps the fluid moving through the filter was more thoroughly mixed. It is important to note, however, that the maximum value at each point was recorded at the same time as when the filter was clogged. This finding indicates that the hydraulic situation was essentially identical whether or not the filter was clogged. Although the exact outcome of this pair of experiments had not been predicted, differences were anticipated. These results have considerable theoretical implications on the measurement and significance of retention time in trickling filters, and this matter will be investigated in greater detail.

In another test, a trickling filter at the Flint River WPC of the City of Atlanta was studied to provide a comparison with the one at the Clayton County plant. Indium tracer plus Rhodine 6B was introduced into the dosing box of one of the two filters of the plant. Samples taken at the filter outlet produced the curve labeled "A" in Fig. 5. Curves B and C represent concentrations at the inlets to the two halves of the divided secondary clarifier. The maximum values at these points are much lower than at the filter outlet because the flow is combined with that of a second trickling filter.

The time of flow from the filters to the clarifier was short and the maximum tracer concentrations occurred almost simultaneously. Curves B' and C' were obtained from samples taken at the outlets of the clarifier and reveal considerable difference in the behavior of the two halves. On the B' side, the trace concentration began at a low value, increased slowly, and then decreased. This indicates that considerable mixing had taken place in contrast to the situation on the C' side where the tracer moved as a compact slug, beginning at a high value for several minutes and then decreasing rather quickly to a lower continuing value.

INDIUM (PARTS PER BILLION)

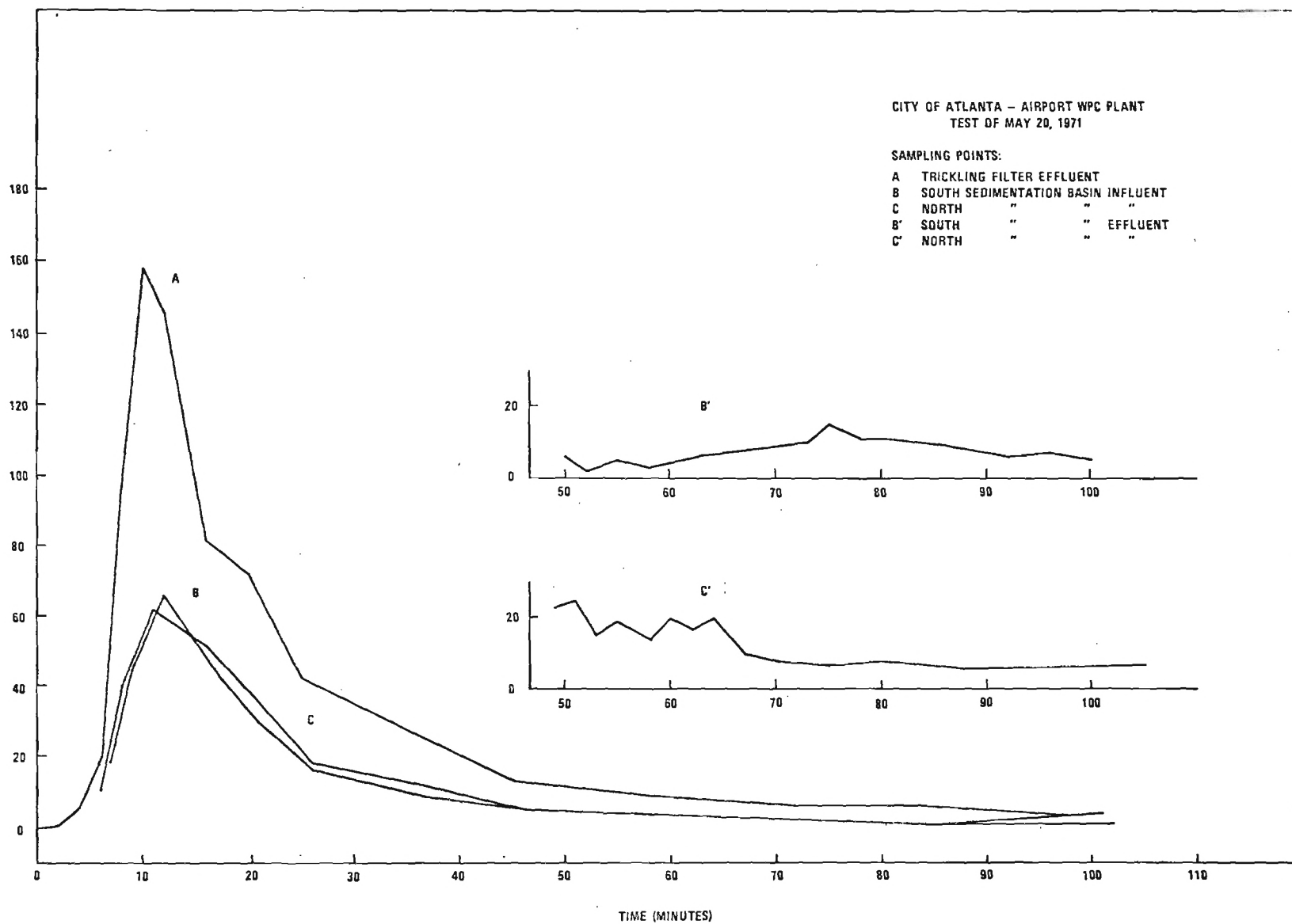


Figure 5. Tracer Concentrations at Points in Atlanta Flint River WPC Plant

According to the plant superintendent, this basin was designed for a two hour detention time, and the appearance of the dye tracer in the outlet after only 45 minutes came as a surprise. The pattern observed on the C' side is clearly indicative of short circuiting and may have been related to the presence of a heavy scum layer covering most of this side. In neither side of the basin was the dye visible except near the inlet and at the outlet. This disappearance of the dye near the inlet indicates a density differential so that the colder influent sinks, moves across the bottom of the tank, and rises to the outlet at the effluent end of the tank. It was concluded from this experiment that short circuiting was actually occurring in both sides of the basin.

#### Sludge Settling

At the outlet of the sedimentation basin of the Sandy Creek WPC Plant, particulate matter was observed passing over the weir and to the plant outfall. In order to study this situation more fully, sludge was labeled with a tracer and the concentration in the effluent measured as a function of time.

Approximately three gallons of sludge were collected from the sump at the sedimentation basin and placed in a five gallon can. Ten grams of indium (as the sulfate) dissolved in a little water were added, and the mixture was heated almost to boiling over a portable propane furnace. The mixture was stirred during the half hour heating period. The odors produced by this procedure leave much to be desired from an aesthetic standpoint.

The hot sludge was then poured into the inlet of the east side of the sedimentation basin and this was followed by a gallon of water containing 200 grams of Rhodine 6B. Color appeared in the effluent at 24 minutes and



sampling was begun. Quart samples were obtained at 3 minute intervals. At 2 minute intervals duplicate 1 ml samples were collected. No dye color was evident anywhere in the basin except at the outlet, and sampling was continued until the color of the effluent had faded to a low level.

Upon return to the laboratory, the quart samples were filtered by suction and the solid matter collected was analyzed. Samples of the filtrate were also analyzed and found to contain indium, although at a much lower concentration than the solids. The results of these analyses are shown in Fig. 6. The concentration of tracer in the sludge is seen to fluctuate in a very regular periodic fashion. Concentrations of tracer in the supernatant also fluctuated in a very similar fashion although not exactly in phase with those of the sludge.

This pattern of behavior is indicative of a pattern of recirculation, with a period of nine minutes. There was nothing about this basin that accounted directly for these results. The sludge scraping mechanism moves very slowly and continuously, and does not seem capable of producing this pattern. This possibility is not to be discounted entirely, however, as the lack of dye color in the basin indicated a density current. It is possible that this current produced a rolling motion as it impinged upon the outlet wall of the basin. Part of the flow would exit over the weir and the balance would roll back toward the basin inlet. Each time this mass of water rotated, the tracer concentration would be lessened by the amount previously lost, and by dilution.

In an attempt to clarify this situation, the experiment was repeated, the only differences being that indium solution was stirred into the sludge without heating and samples were collected at one minute intervals. The results of this second run are shown in Fig. 7 where it is seen that the

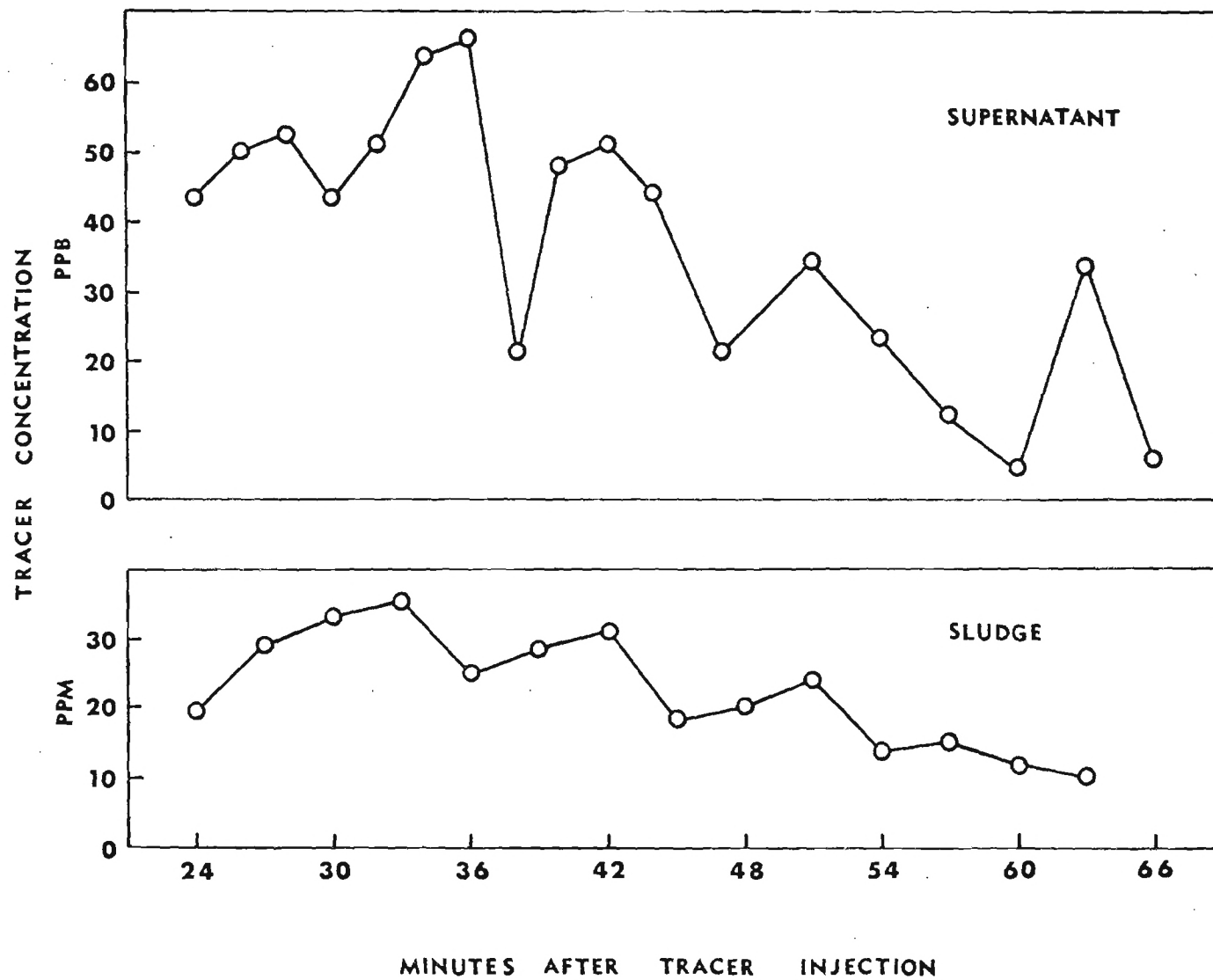


Figure 6. Indium Concentration in Sludge and Supernatant--First Test

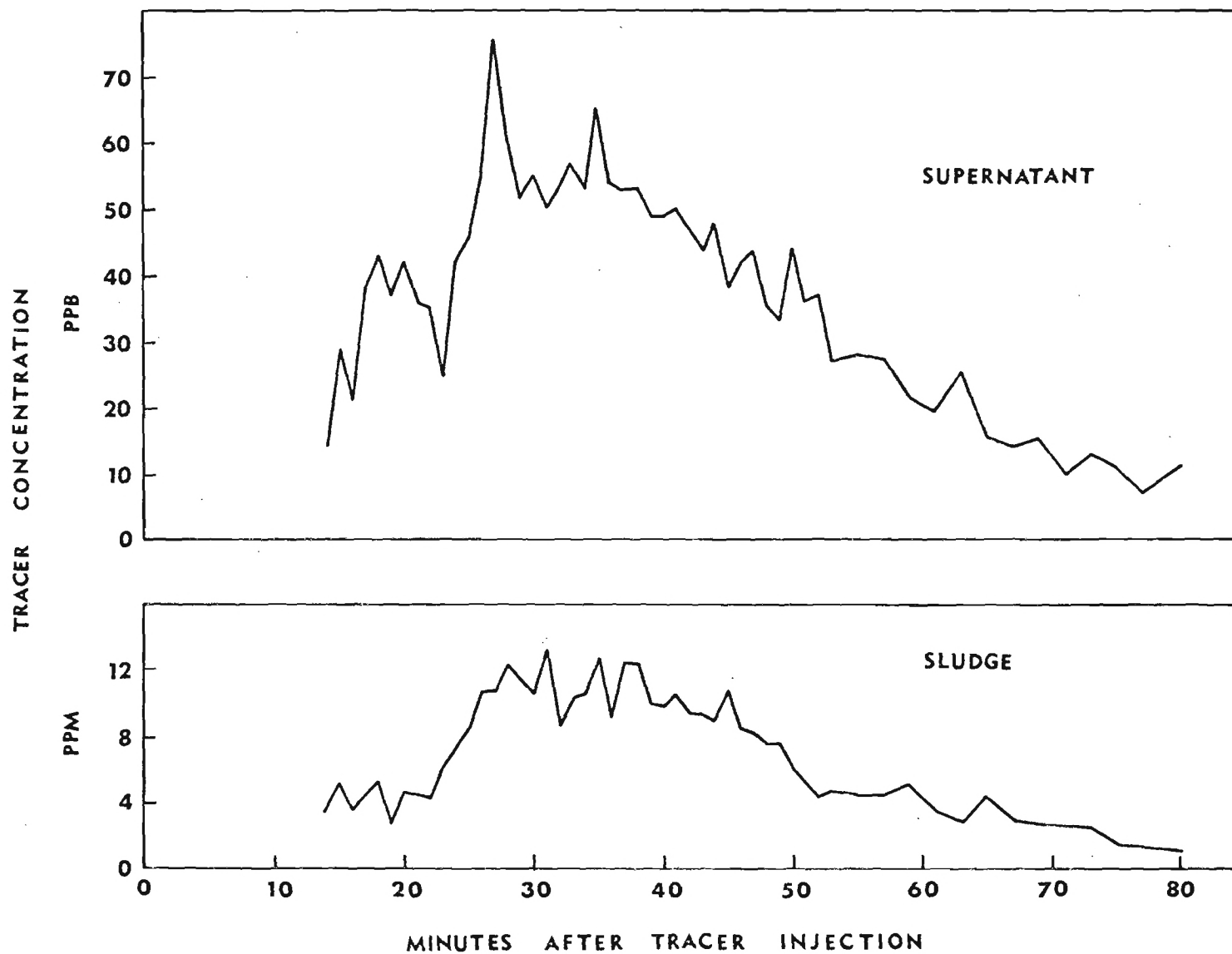


Figure 7. Indium Concentration in Sludge and Supernatant--Second Test

pattern is entirely different from that of the first test. At the time of the second run, the recirculation pattern was absent and tracer concentrations rose to a rather ill-defined maximum and then gradually decreased.

As other conditions about the basin appeared to be the same as previously, the maximum tracer concentrations of the two runs are taken as some indication of the efficiency of solids collection. The second situation when the indium maximum was only about 12 ppm is taken to indicate better operation of the basin than in the first test where tracer concentration went above 30 ppm.

#### Radioactive Tracer

To obtain comparative data for radioactive tracers and stable tracers, an experiment utilizing 15-hour sodium-24 was performed at the Sandy Creek WPC Plant. Extensive planning was required, as it was necessary to obtain permission to use a radioisotope from the Radiation Protection Committee of Georgia Tech, the waste treatment authorities of the City of Atlanta, and the Georgia State Health Department. After agreement of all parties concerned had been obtained, the radioisotope was prepared by irradiation of sodium carbonate in the Georgia Tech Research Reactor. The dry powder was placed in a closed but unsealed polyethylene vial and irradiated for a period of time calculated to produce approximately 150 millicuries of activity. Gross activity measurements of the irradiated vial showed that slightly more activity was produced than had been calculated.

The vial containing the isotope was placed in a lead pig, placed in an approved shipping container, and transported to the plant site in a truck bearing "Radioactive" placards. This truck was driven by a staff member of the Georgia Tech Office of Radiological Safety who also monitored subsequent operations in the field. All personnel connected with the work wore film

badges or thermoluminescent dosimeters. No reportable ( $> 40$  mR) doses were incurred.

The radioisotope was prepared for use by submerging the irradiation vial in water contained in a one-gallon wide-mouth plastic jar. The vial was squeezed with long-handled tongs, and this forced off the lid of the vial. It was emptied and rinsed in the water. The tongs were then used to pour the active solution into the inlet of the sedimentation basin. A solution of Rhodine 6B was poured simultaneously into the inlet of the east side of the basin.

As this sedimentation basin is divided, the tracer moved through only one side. The flow is combined at the basin outlet, so the radioisotope concentration was reduced to one half by dilution prior to release to the river.

Field instrumentation for this experiment consisted of a sodium iodide scintillation detector with a scaler. The scintillator probe was wrapped in several layers of plastic and was positioned in one of the troughs of the outlet weir, where it was submerged to a depth of one or two inches. Also utilized on site was a sodium iodide scintillation detector connected to a single channel analyzer. The crystal was located in a lead shield, and 10 ml samples in polystyrene vials with polyethylene caps were counted in a 5 volt window about the 1368.4 keV sodium photopeak.

The immersed scintillation detector was much too sensitive for the selected geometry, and the lower sensitivity settings of the scaler were later found to be difficult to correlate. The majority of the readings were taken at the same setting, however, so that most of the results are self consistent. With the exception of a couple of points, the readings agreed quite well with the results obtained from the single channel analyzer. The results of both methods of analysis are plotted on the graph of Fig. 8.



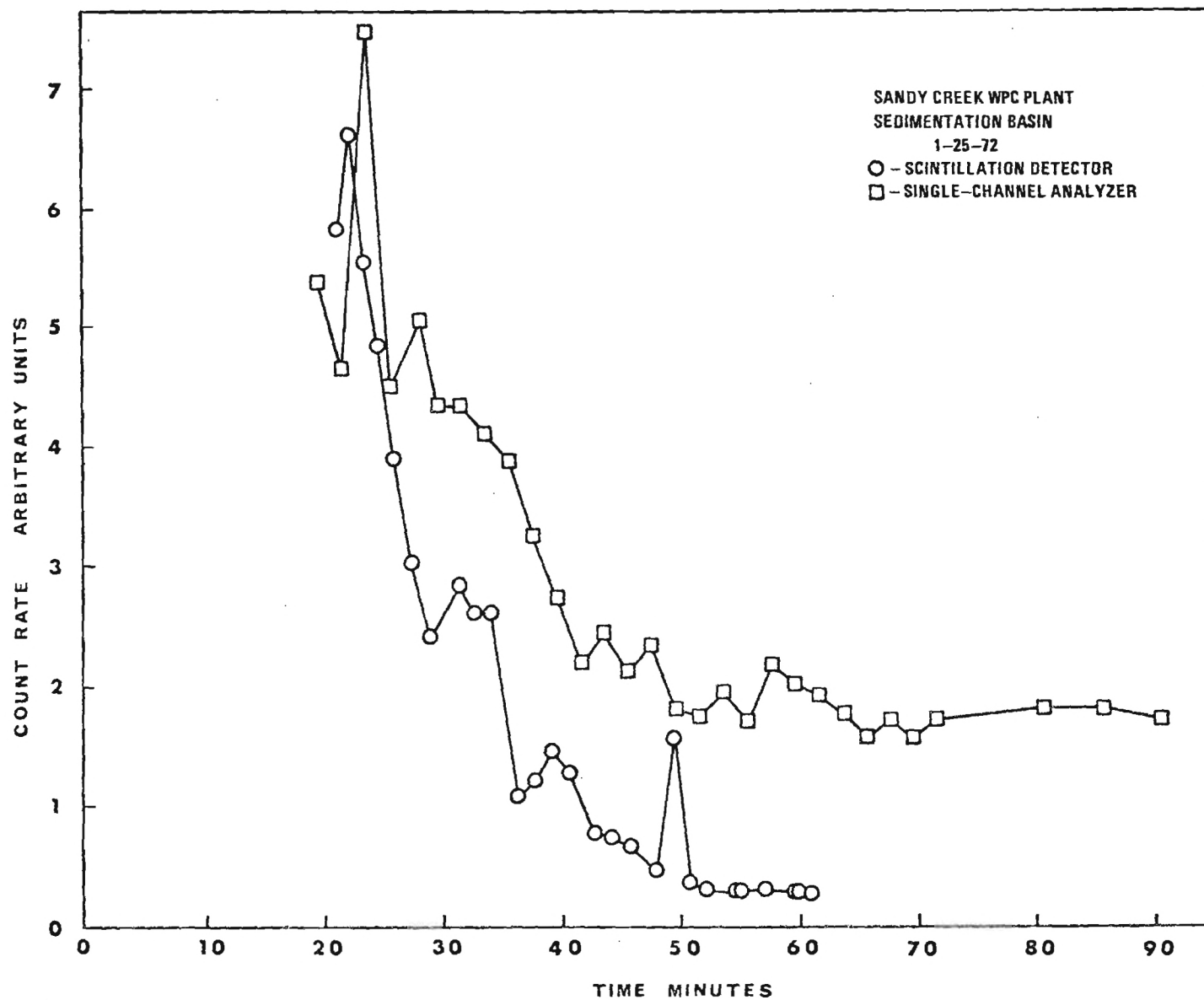


Figure 8. Field Measurements of Radioactivity at Sandy Creek WPC Plant

The samples were returned to the laboratory and on the following day were counted on the semiconductor detector and gamma-ray spectrometer system regularly used in the neutron activation work. Additionally, the entire spectrum of the samples was counted on a scintillation detector. Findings of the latter determinations are detailed in Fig. 9.

It will be noted that on all of these curves the concentration was decreasing rapidly in the period of 30 to 40 minutes following tracer injection. At 42 minutes, the sludge scraping mechanism was turned on, and the pattern of concentrations changed. The rate of decrease lessened and was fairly constant during the last 20 minutes of the experiment. These findings give credence to the belief that operation of the sludge scraper, although moving very slowly, does indeed influence the flow pattern in the basin. There was also visual evidence from the behavior of the dye. During the early stages of the run, no dye color was visible except at the outlet weir, where the flow rises to enter the effluent trough. After the flights began to move, color became evident throughout the basin, even in the first quarter of the tank. It was apparent that the liquid containing the dye was being mixed with the overlying sewage of normal gray color.

From the results of this test, it is concluded that the movement of the sludge collecting mechanism exerts a major influence on the pattern of fluid movement within the basin. The desirability of interfering with the natural pattern would depend on the manner in which a basin is operating. A temperature differential which moves flow directly to the lower section of a tank admittedly carries suspended matter quickly to the bottom, but as the flow involves only a fraction of the cross-sectional area of the tank, the velocity is many times greater than intended. Solid matter is therefore swept along in the current, and efficiency of sedimentation is poor. Under

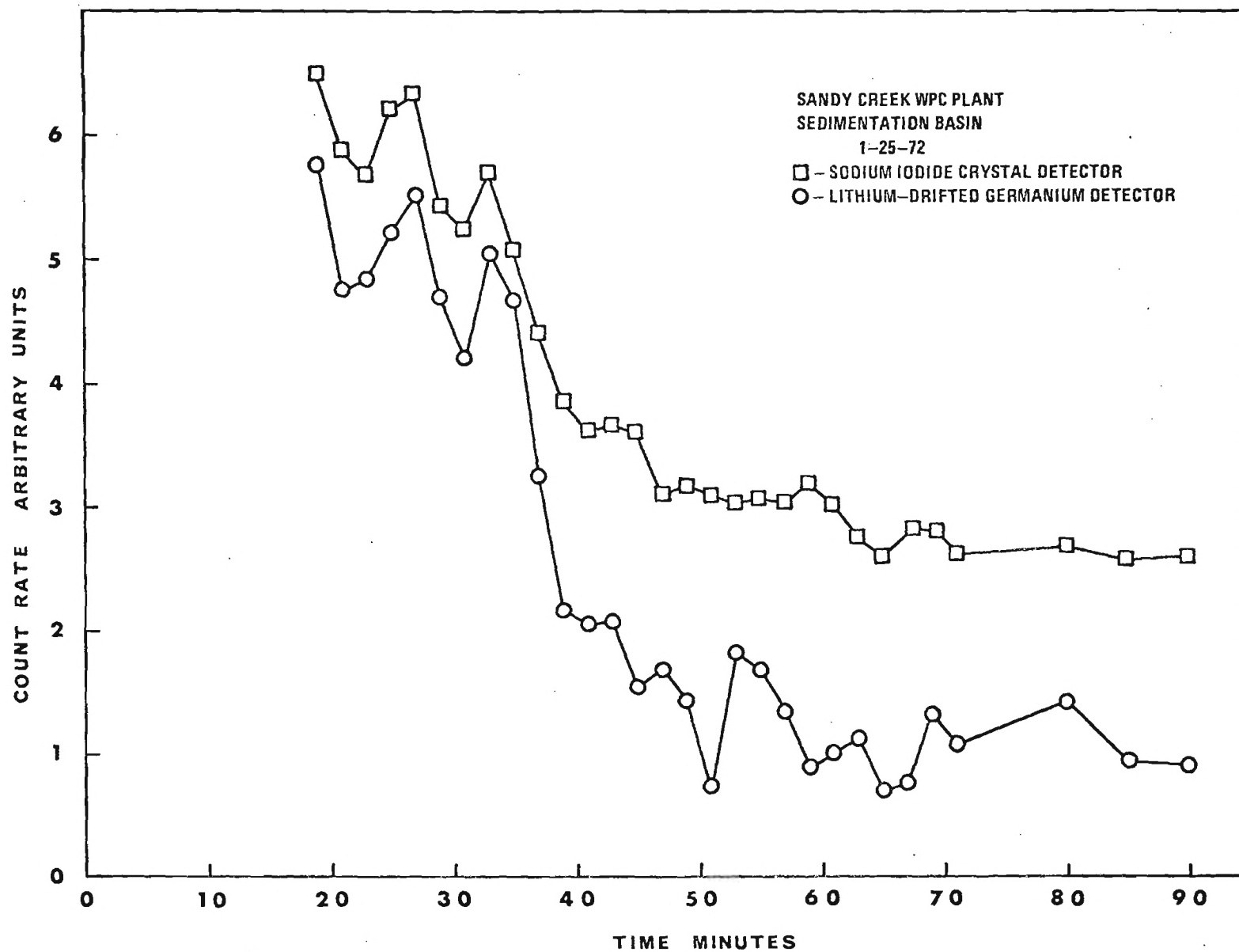


Figure 9. Laboratory Measurements of Radioactivity from Samples Taken at Sandy Creek WPC Plant

these conditions, an interruption in this flow pattern would be advantageous. However, if there were no short circuiting in a basin, the movement of liquid induced by the motion of the sludge scraping flights might hinder the settling of suspended matter.

## DISCUSSION

The test work described here has shown clearly that the use of stable tracers with post-sampling activation analysis is practical in sewage treatment plants and can yield valuable data of practical significance. While the time delay in analyzing the samples is a drawback compared with the instantaneous indication available with radioactive tracers, the lack of red tape and the psychological problems associated with the use of anything radioactive in the public domain tend to balance this. Presentation of some of the results of this work to the Georgia Water Pollution Control Association has elicited interest and probable ready acceptance of this procedure. Subsequent work will, of course, need to follow up this approach to ensure wider utilization of the method.

In two instances, plant superintendents were aware of basin short-circuiting, but had no idea as to the severity of the problem. Although this is not a matter that can be changed by any simple means, the tests helped explain some of the poor operating results that have occurred from time to time. The discovery of a very regular periodic recirculation pattern in the Sandy Creek basin was not anticipated, and was viewed with great interest. It is obvious to all concerned that a moving object will influence the flow pattern in a basin, but the magnitude of the effect was enlightening. Further work is needed to verify that the sludge collector is the cause of this phenomenon, and to determine if a different schedule of operation would give better efficiency. Further test work is needed to demonstrate applications to other types and portions of treatment plants, especially for sludge handling.

The cost of the test work also needs evaluating on a realistic basis. Indium is a relatively expensive tracer material to use, and there is an incentive to use a cheaper material for those systems where this appears to be practical. Similarly, the activation services and gamma-ray analysis can be performed at lesser cost once the development phase is past. If the sampling can be done by the normal plant operating personnel, a major cost factor can be eliminated. These and related aspects will be studied in subsequent work.



## CONCLUSIONS

The work described in this report has shown that post-activation analysis of stable tracers offers a simple approach for the evaluation of sewage treatment plants, with considerable advantages over dye tracers and radio-tracer tests used commonly in water studies. It is felt that there would be few obstacles to acceptance by the industry and, with some training, the cost of testing and sampling can be reduced to a level easily compatible with the benefits derived from proper operation of all water pollution control facilities.

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#### PAPERS PRESENTED

Craft, T. F., "Tracer Methods for the Evaluation of Waste Treatment Processes," Georgia Water and Pollution Control Association Annual Conference, Augusta, Georgia, September, 1971

Eichholz, G. G., "Use of Post-Sampling Activation Analysis in Sewage Treatment Plants," American Nuclear Society 1971 Winter Meeting, Miami Beach, Florida, October, 1971

## EVALUATION OF TREATMENT PLANTS BY TRACER METHODS

January 15, 1971 - March 15, 1973

## Final Report

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## ABSTRACT

To overcome the practical difficulties associated with the use of radiotracers or dye markers in evaluating the performance of sewage treatment plants, the use of stable elemental tracers followed by post-sampling neutron activation analysis has been investigated. Of the various possible tracer elements, indium offers the greatest attraction on account of its high neutron capture cross section, its absence from most natural waters, and its low toxicity. Tests have been performed to establish the most convenient procedure for using tracers in soluble form or adsorbed on various particulates in investigations of treatment plant performance.

Field tests have been conducted at several treatment plants in the Atlanta, Georgia region. The performance of sedimentation basins, trickling filters, and activated sludge tanks has been studied and abnormal operating conditions have been demonstrated in some cases. It was shown that the inert tracer method, coupled with subsequent activation analysis provides a powerful and convenient method of testing the performance of treatment plant characteristics. Inert tracers are easier to introduce into the normal plant routine than radioactive tracers would be and results can be made quantitative with greater assurance than any dye tracer.

## INTRODUCTION

The treatment of municipal wastes by sedimentation and biological oxidation processes is the most widely practiced method of waste treatment and our first line of defense against large-scale environmental pollution. The growth of urban populations in recent decades and the steady increase in water usage for industrial and domestic purposes has imposed a heavy burden on existing facilities, many of which are operating well beyond their design capacity a great part of the time. In addition, it is not often easy to determine precisely whether the various component parts of a plant are operating at or near optimum design conditions, and they may be functioning well below their proper level for long periods before this fact becomes evident. It is, therefore, of prime importance to introduce methods of testing and diagnosis to the operating plants that can yield needed data without interfering with system operations and by methods that can be handled by present plant personnel.

Tracer methods consist of the addition of an identifiable material to the stream under investigation. If the tracer material is comparable in behavior to the flowing matter being studied, either by being soluble in the fluid or being attached to any suspended matter, then its movement in the fluid can be used to indicate such parameters as flow velocity, residence time, flow paths or segregation of components. In treatment plants, flow paths, recirculation paths, effective tank volumes, residence times, and mixing rates are of prime interest. The test work was, therefore, designed to illustrate some of the measurements of that type in representative, operating plants. On occasion considerable, unexpected deviations from normal conditions were found that had not been previously suspected by the operator.

Radioactive tracer methods have been investigated in a wide range of hydrological and plant flow applications for many years, and their utility has been well established. Nevertheless, such tracer methods have found few routine industrial applications in the United States, despite the advantages offered by their use. There appear to be several reasons for this non-use. The first is lack of familiarity; in spite of the number



of papers written on the subject, these have usually been written by radioisotope specialists for other isotope specialists, and only rarely have they been presented to groups in the trade or industry concerned. The second is technical; the use of radiotracers and of specialized counting equipment requires a level of expertise and sophistication beyond the typical plant supervisor. The third is psychological; the use of radioactive materials is still approached with considerable fear and reluctance by the layman. In addition, the red tape involved in obtaining the necessary licenses and permits acts as a deterrent. The last one is environmental; there is a growing reluctance to add, or permit to be added, any radioactive material, however low in amount, to any open stream or unconfined water system. The net effect of these factors is to almost preclude the use of radioactive tracers in any municipal treatment system, except under special conditions and for research purposes.(1)

In order to overcome this problem and to make available to the water pollution control industry the benefits of the tracer method and the large amount of associated work done, most of it under U.S. AEC auspices, alternative approaches have been explored both to make the method more acceptable to the industry and to provide for training and information transfer in this area. This was the primary purpose of the present project. This report constitutes a summary of the work done during the past two years.

#### Method of Attack

There are several parameters in the operation of sewage treatment plants that are of significance in assessing the existing plant conditions and operating efficiency. These include the flow rates in various parts of the system, residence times, flow paths, and recirculation paths. All of these parameters are accessible to tracer methods by well-known dye and radiotracer procedures. Difficulties may arise from the presence of suspended matter, the turbidity of the water involved, and, of course, the open-air situation of such plants.

The main purpose of this project was to investigate the feasibility of stable, i.e., non-radioactive, tracers in indicating plant performance parameters, to evaluate the relative usefulness of such tracers compared with alternative tracer methods, and to insure information transfer to

segments of the industry to facilitate use of the method and procedure to the greatest possible extent. Dye and radioactive tracers were also used on occasion for comparison with previous work.

The general approach was to use a trace element not normally found in local water, such as indium, add it in trace amounts to the flow system under study, and determine its appearance in subsequent samples by later subjecting them to neutron activation in the Georgia Tech Research Reactor. This approach has the advantage that only a small amount of inert solution is required so that both the injection and sampling can be carried out by unschooled personnel. No pollution of water by radioactive material occurs, and the tracer addition is well below any toxic level. The need to collect and convey a large number of samples to a reactor facility for activation and counting is a drawback, but no different from the procedure employed in tritium tracer work widely used in hydrological investigations. Small university and research reactors are found in many locations throughout the country, so that this step need no longer be considered a major obstacle.

Since the initial results to be obtained were essentially qualitative and to be used in the light of the operator's experience with the normal functioning of his own plant, it was important to devise a procedure that was simple to adapt to local conditions. It was necessary to select sites and subsystems that were representative of good practice and conventional design so that the results obtained could be readily compared to other systems and the utility of the approach would be obvious to other operators.

Through the courtesy of the City of Atlanta Water Pollution Control Division and the Clayton County, Georgia, Water Authority, tracer tests have been done at several of their treatment plants using dye and stable tracers, as well as a radioactive tracer in one case. These tests have shown the existence of normal and abnormal flow patterns, differential residence times, and in some cases unexpected recirculation patterns. They have indicated the advantages and disadvantages of this approach and will be described in detail below.

Post-sampling activation analysis differs from conventional radioactive tracer work in several respects. Whereas in the case of radioactive tracers in stream studies, it is helpful to have comparable inert carrier material

present to avoid radiocolloid formation and excessive fractionation, the use of stable tracers requires the choice of a material that is normally completely absent from the water under test. Since the amount of inert tracer used is governed entirely by considerations of expected dilution, detectability, and cost, it is important to select a material that is environmentally acceptable and completely non-toxic in the concentrations expected. Since sewage is not naturally ingested, only effluent concentrations need be considered here. Another important difference compared with radiotracers lies in the choice of the activated isotope. After sampling, the test sample is exposed to neutrons in a nuclear reactor and the induced radioactivity is detected and counted. To be readily detected the tracer must have a high thermal neutron cross section and a good specific activity after activation. This implies a fairly short half life, certainly much shorter than would be convenient for radiotracer field tests. In addition, the gamma rays emitted should be readily discriminated against those from other trace elements normally present in the waste waters, notably sodium, which will be activated at the same time.

An essential part of the project, therefore, has consisted of selecting tracer elements that meet the above criteria and developing methods for injecting them into the systems, as well as for attaching them to suspended solids characteristic of those found in the waste water. Subsequently, demonstration tests were run at other plants, notable at Macon, Georgia to familiarize some plant operators with the concepts and techniques involved.

## EXPERIMENTAL DETAILS

In order to evaluate the operation of treatment plants by tracer methods, it was decided to concentrate on the following aspects:

1. Selection of tracers to be used in terms of ease of detection by activation analysis, availability, and acceptable cost;
2. Methods of tagging or attachment to suspended solids;
3. Background determinations of existing trace elements in waste waters and identification of possible interferences;
4. Field tests on portions of treatment plants to evaluate the sensitivity of the tracer and to compare the post-sampling activation analysis procedure with both dye markers and radioactive tracers;
5. Interpretation of results in terms of plant operations; and
6. Information transfer to the pollution control industry, initially in the local region.

### Selection of Tracer Material

In order to be useful as a stable tracer for subsequent detection by neutron activation, an element must possess a number of particular characteristics. To convert the tracer sample to a radioisotope of sufficient activity to be measurable requires that the target elements be present in the plant system in sufficient concentration, that it have a reasonably large thermal neutron capture cross section, and that it produce a radioisotope of suitable half life and decay properties. The importance of the chemical properties of the element depends to some extent on the condition of the experiment and on whether or not absorption of the tracer on a substrate is desired. When the trace element is to be used in soluble form, availability of a readily soluble salt is essential. Toxicity and cost must also be considered.

When a particulate is to be labeled, firm attachment of the tracer is sought, whereas in flow measurements, where the tracer is used in dissolved form, minimum absorption or adsorption on any particulates present is desired. Another important factor is the possible prior presence of the same element in the system to be studied. Complete absence would be best, of course, but it is often possible to subtract out any existing known background concentrations as long as it is not excessive. Manganese

falls in this category, as it has appropriate nuclear and other properties, but is found almost invariably in the waters of the Atlanta area. Some potentially useful elements are quite expensive and this may limit their use. A number of elements have suitable characteristics and Table I summarizes the nuclear properties of several of those investigated. Indium was selected as the most suitable tracer in most of the work; scandium, manganese, and bromine have also been used. It may be of interest to note that Dahl et al. in Sweden (2) have also chosen indium in independent studies, whereas Kruger and Channell (3) have used rare-earth tracers.

To determine the suitability of these materials, both as soluble tracers and as adsorbed tracers on particulates, activation analyses were run on blank water samples and on known solutions. The blank samples established the presence or absence of background trace concentrations in local water samples for the element concerned. The known samples served to determine the sensitivity of the selected activation procedure for that element, to calibrate the gamma-ray spectrometer, and to indicate any interfering activity peaks from other trace elements.

For tracer tests on particulates, it was also important to find if a suitable labeling procedure could be developed.

#### Tagging Tests

Laboratory experiments have been performed to evaluate the ease and effectiveness of incorporating a tracer element into organic and inorganic particles. For tracer tests on suspended matter the optimum situation would be to have a batch of particles of chosen size each containing some tracer attached so firmly that it would not be dissolved away or leached out on prolonged exposure to water. The density as well as the size of the labeled particles should be the same as those of the whole groups of particles whose movement is to be traced.

It has been demonstrated previously that the high cation exchange capacity of vermiculite can be utilized in the preparation of radioactive tracer particles (4). Ground vermiculite is slurried with a solution of the tracer cation, dried, calcined, and reground. The desired size fractions



Table I. Elements Considered for Tracer Use

Element	Isotope Measured	Abundance (%)	Cross Section (barns)	Radionuclide	Half Life	Principal $\gamma$ Energy (MeV)
Sc	Sc-45	99.99	13	Sc-46	83.9 d	0.889
						1.12
Cr	Cr-50	4.31	17	Cr-51	27.8 d	0.32
Mn	Mn-55	99.99	13.3	Mn-56	155 m	0.847
Co	Co-59	99.99	19	Co-60	5.26 y	1.173
						1.33
Br	Br-81	49.31	0.2	Br-82	35.2 hr	1.811
Mo	Mo-98	23.75	0.51	Mo-99	66.7 hr	0.181
						0.739
						0.778
In	In-115	95.77	1.54	In-116	53.7 m	1.293
Ce	Ce-140	88.48	0.6	Ce-141	32.5 d	0.146
	Ce-142	11.07	1.0	Ce-143	33.7 hr	0.293
Ta	Ta-181	99.99	21.0	Ta-182	115 d	1.221



are obtained by sieving. Scandium and indium on vermiculite have now been prepared by this method. Other inorganic carriers studied included kaolin, glass frit, and bottle glass.

In the present work, organic particles that have been subjected to labeling procedures include sewage sludge, oatmeal, grits, and wool. The general technique was to stir the organic particulates into a solution containing the desired element. Half of the mixture was boiled while stirring and the remainder was stirred cold. Wool was not treated by this technique, but was mordant dyed, using the desired cation as the mordant. Effectiveness of the labeling procedure was evaluated by activation analysis of the particulate matter, the decantate, and several successive wash waters. Details of representative experiments and results follow.

#### Vermiculite

Ten grams of vermiculite ground to pass a 100 mesh screen were slurried for several hours in water containing 20 mg of indium sulfate. After standing overnight, the liquid was decanted and the solid residue transferred to a quartz dish. It was dried under a heat lamp and then heated to 2050°F in a muffle furnace. After cooling, the sintered mass was ground to a ball mill. Neutron activation analysis of water in which the ground solid was soaked for several hours showed a count rate of zero compared to 44,000 for solid irradiated simultaneously, confirming the high stability of tracer attachment. This procedure has also been used with scandium as the labeling element and with kaolin as the substrate. All give similar results. The high resistance to leaching is believed due to diffusion of the tracer into the particles and also a surface melting of the particles sealing off the active exchange sites. Previous work in this laboratory (5) has shown that in vermiculite treated in this manner the tracer concentration is independent of particle size, indicating that the attachment of tracer ions is not merely a function of surface area.

#### Glass

Tracer elements stirred into molten glass yield particles that are very resistant to leaching. The procedure consisted of melting about 200 grams of bottle glass or glass frit (Pemco brand) in a pot furnace. Bottle

glass melted in the range of 1000-2000°F. The tracer element in dry form (indium sulfate, molybdenum trioxide, scandium oxide) was then stirred into the melted glass. After allowing the melt to soak for a while, it was poured into cold water. The resulting strands and particles of glass were then ground in a ball mill.

#### Organic Substrates

Sewage sludge, oatmeal, and grits have all been subjected to a similar labeling process. A typical procedure was to prepare instant oatmeal by mixing it with hot water. It was then cooled, a solution of the tracer element added, and the mixture stirred. It was then divided into two portions--one of which was stirred while heating, the other stirred cold. After half an hour the solids were allowed to settle until a reasonably clear sample of the water could be obtained. The solid was then washed with several portions of water, each time separating the solids by settling. Samples of the solid, the initial decantate, and the wash waters were then analyzed for tracer content.

The results were not very precise due to the variable moisture content of the sludge, but they gave the relative distribution of the tracer between the solution and the sludge in the form it would be utilized. The results of several experiments are summarized in Table II for various materials. There appears to be no clear-cut advantage in boiling the mixture. Grits seem to be an unsatisfactory medium for this purpose.

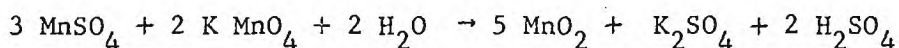
Table II. Ratio of Solids/Decantate Indium Concentrations in Labeling Experiments

Substrate	Unboiled	Boiled
Sewage Sludge	3.8	1.54
Oatmeal	1.64	2.02
Oatmeal	1.45	0.81
Grits	1.90	0.80
Grits	0.32	0.92
Grits (cobalt tracer)	0.36	0.69

### Sludge Labeling with Manganese

The ease with which manganese is activated and the convenient half-life of 155 minutes of the Mn-56 formed makes it an attractive choice for tracer work. The major disadvantage is its common occurrence in natural waters at low but readily observed levels. This disadvantage may be overcome by use of enough tracer to raise the manganese level distinguishably above the background which is typically 1-2 ppm in the Atlanta, Georgia area.

It was found that manganese can be attached to particles of sewage sludge very conveniently. Manganous sulfate and potassium permanganate react according to the equation:



If this reaction is carried out by stirring solutions of the reactants into a slurry of sewage sludge, manganese dioxide is formed and deposited in and on the sludge particles. No precipitate of manganese dioxide can be observed in the reaction vessel.

Sludge labeled with manganese by this procedure was used as a tracer on several occasions and proved to be satisfactory. Typical collected samples are mostly water and contain only a small amount of the labeled solid. Some of the deposited manganese apparently enters the liquid phase while the sample is being held and/or transported to the laboratory for analysis, but the equilibrium concentration is low. All samples from any given test are treated in the same manner, and it is believed that re-solution introduces no appreciable error.

### Neutron Activation Analysis

Samples to be analyzed were placed in polyethylene vials, heat-sealed to prevent leakage, and then placed in a plastic "rabbit" for insertion into the Georgia Tech Research Reactor via the pneumatic tube facility. The rabbit will hold six of the small irradiation vials; five samples plus a standard were loaded for each irradiation. Standards were prepared from high purity reagents, carefully weighed, dissolved, and brought to exact volume in a volumetric flask.

While the neutron flux in the reactor is essentially constant, some fluctuation does occur and maximum precision is ensured most easily by including a standard in each irradiation. This also eliminates the effect of possible errors in positioning or in timing, a matter of major importance with isotopes of short half-life.

The neutron flux in the reactor pneumatic tube system is about  $1.2 \times 10^{13}$  neutrons/cm<sup>2</sup>/sec, and the irradiation time for each group of samples was adjusted to provide a suitable count rate for the concentration of the particular element under consideration. In the case of indium, the most frequently used tracer, an irradiation period of one to five minutes produced sufficient activity for satisfactory results with counting intervals of 100 or 200 seconds (live time).

Samples were counted by a 60 cc lithium-drifted germanium detector used in conjunction with a 1024-channel pulse height analyzer, Nuclear Data, Model 2200. The system was interfaced with a Hewlett-Packard Model 9100B Computer that was programmed to calculate the net number of counts in any selected  $\gamma$ -photopeak area (6). This array of equipment served particularly well for the handling of the dozens of samples associated with each field experiment. For best efficiency, two workers were required--one to handle irradiations and carry samples to the counting area and the other to operate the counting system and record data.

As a larger number of samples was being collected and analyzed, it was decided to automate the calibration and analyzing procedure to the greatest extent possible.

The sample was counted on the cap of a GeLi detector for 400 seconds live time. Then the spectrum was scanned by the MCA Peak Picker program of the Hewlett-Packard desk computer.

In preparation for the counting the samples, the energy per channel and the zero energy offset were calculated by another program written for the Hewlett-Packard computer. The coarse gain on the multichannel analyzer (MCA) had been set for approximately 2 keV per channel, giving an energy range of approximately zero to 2 MeV for the 1024 MCA. A spectrum for Na-22 was acquired to provide fixed energy points at the gamma-ray energy of 1274.6 keV and the positron annihilation peak at

511.0 keV. The energy calibration was stored in the memory by locating the Na-22 peaks. Then the MCA Peak Picker was loaded. A statistical test factor of 3 was used in the program to determine a peak. This statistical test factor inserts a test requiring a peak to be greater than three times the standard deviation of the background for the program to identify it as a peak.

Occasionally a second count of the samples was taken in order to obtain data for calculation of half-lives of the isotopes when unknown elements required identification.

The procedure for the samples irradiated for 1 hour was similar, except that the samples were allowed to cool for one day after irradiation. For an unknown spectrum containing a complex array of photopeaks a computer program SPECTRAN was used. This is described in detail in Appendix A. Its main function is to locate all photopeaks in the spectrum, test them for their statistical validity in relation to the Compton background and match their energy to the spectrum of known elements. Through perhaps a little more elaborate than is necessary in routine tracer tests, the availability of such a computer procedure can save much time and effort at a later stage.

#### Sampling Procedure

For the field tests at sewage treatment plants, liquid samples were collected from tanks, channels, and other locations by dipping with a can attached to a stick of suitable length. Plastic tape was used to secure the stick to the lower side of the can so that it was self supporting when placed on a flat surface. The cost of these samplers was so trivial that they were intended to be disposable, but because of their durability and convenience, they have been used repeatedly and should be satisfactory indefinitely. The self-supporting feature is important because, after a sample is collected, portions must then be transferred to irradiation vials, a procedure requiring two hands. The polyethylene vials have a capacity of slightly more than one milliliter and they were supported in wooden blocks containing holes into which they fit snugly. Both the holes, the vials, and the blocks were marked



for positive identification. Because of the possibility of contamination due to sample spillage, new wooden blocks were used for each experiment. Liquid was transferred from the sampling container to the vials by a one-milliliter disposable pipette attached to a 10-milliliter syringe.

During a run, the sampler was rinsed in the liquid to be sampled a few seconds before the moment of collection. After the sample was obtained, the pipette was then rinsed with one or two portions of the sample, and the desired samples pipetted into the vials. The sample was stirred with the pipette if any rapidly-settling solids were observed. Duplicate or triplicate samples were collected, and the vials closed with their attached lids. They were then ready for transportation to the laboratory for analysis.

When the solids content of a flow was to be considered separately from the liquid, larger samples were required. Pint milk bottles were used and were filled by dipping by hand at the desired location. Card-board stoppers for these bottles were not available, so squares of aluminum foil were used as closures. The bottles were conveniently transported in milk bottle crates.

In the laboratory these samples were filtered by suction in a Buchner funnel. After all the liquid had passed through, the filter paper was folded and forced into an irradiation vial. Portions of the supernatant were pipetted into other vials for separate analysis.



## FIELD TEST WORK

The laboratory work aimed at developing procedures for detecting the stable tracers by activation analysis and for testing labeling methods for particulates proceeded more or less in parallel with the field tests. These tests were conducted with several purposes in mind: to develop the most convenient methods of injecting and sampling the stable tracer solution; to illustrate the utility of this approach for a variety of real problems that will occur in typical treatment plants; to compare the stable tracer method with the better-known radioactive tracer method and dye marker method under comparable conditions; and to expose and "indoctrinate" plant operating personnel to such test work.

The following sections describe the various plant tests performed.

### Sites of Field Work

#### Sandy Creek Plant

Much of the field work was carried out at the Sandy Creek Water Pollution Control Plant of the City of Atlanta. This facility was chosen because it is one of the smallest of the municipal plants in the area and is reasonably close to Georgia Tech. It is located off Carroll Drive in Northwest Atlanta and is a one million gallon per day (MGD) primary treatment plant serving a small section of Metropolitan Atlanta between Bankhead Highway and Gordon Road. This plant is a small compact basic unit consisting of screen and grit facilities, two 52' x 12' primary settling tanks, one 40' diameter sludge digester, three sludge drying beds, and basic administrative facilities. Figure 1 is a flow sheet of this plant.

This plant is operating at present under less than ideal circumstances as it is overloaded to approximately twice its rated capacity as a result of high density housing conditions that have developed in the area. While this situation is very undesirable from the standpoint of the plant operator, it afforded an opportunity to study operations under difficult conditions.

#### Flint River Plant--Clayton County

The Flint River Sewage Treatment Plant of the Clayton County Water Authority is located about 15 miles south of Atlanta, just southwest of

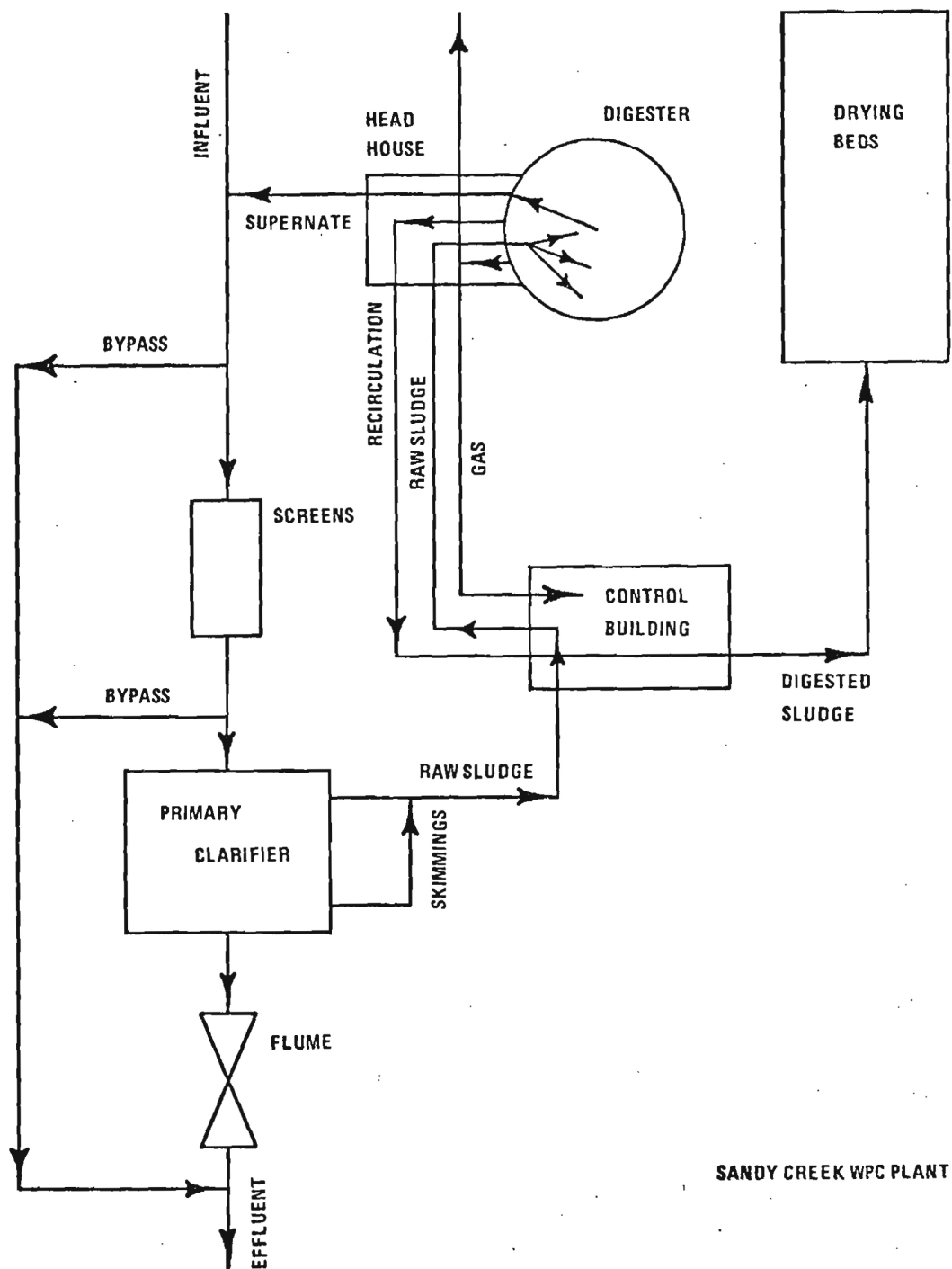


Figure 1. Flow Diagram of Sandy Creek WPC Plant

Jonesboro, Georgia. It is a 3 MGD standard-rate trickling filter plant and consists of four primary and two secondary clarifiers, a 136' diameter trickling filter, two digestors, sludge drying beds, chlorination facilities, and an administration and laboratory building.

Due to growth in the area served by this plant, the present sewage flow is about  $4\frac{1}{2}$  MGD, an overload of 50% of the design capacity. Until an expansion of the present facilities can be completed, this overload situation will continue. Attention was directed to this plant because of difficulties that were being encountered in the operation of the trickling filter.

#### Original Flint River Plant--Atlanta

The Flint River Water Pollution Control Plant of the City of Atlanta is located at the Atlanta Airport near Interstate 285 in northeast Clayton County. It is a 2 MGD standard-rate trickling filter secondary treatment plant consisting of the following equipment: two 68' x 20' rectangular primary clarifiers, two 136' diameter standard-rate trickling filters, two 68' x 20' final settling tanks, two 45' diameter sludge digestors, six sludge drying beds, basic chlorination facilities, and administrative accommodations.

The site of this plant was needed for airport expansion, and a new plant has been constructed nearby. The trickling filters in this plant operate in good, normal fashion and were studied to provide base data for comparison with trickling filters elsewhere that were not functioning properly.

#### New Flint River Plant--Atlanta

The new Flint River Water Pollution Control Plant of the City of Atlanta began operation in 1971 to replace the original plant described above. It was designed to handle 6 MGD but at present is receiving about 3 MGD. About one-third of the plant influent consists of industrial wastes which are produced at the Atlanta airport, a large automobile assembly plant, and other manufacturing facilities. The balance of the plant flow comes from areas that are primarily residential.

The plant is basically designed for activated sludge, but is notable for its flexibility. Provisions are made for introducing primary tank

effluent at several points along the aeration basin, and for close control of the air supply. Return sludge passes through a reaeration basin, although it can be returned directly to the aeration tank if desired. Both aerobic and anaerobic digestors are provided, and digested sludge is dewatered with a centrifuge. An incinerator is also installed.

#### South River Plant

The South River Water Pollution Control Plant of the City of Atlanta is located on Jonesboro Road in southeast Atlanta. It is a modified activated sludge secondary treatment plant made up of two basic treatment phases and one sludge treatment phase. The basic units are a 12 MGD modified activated sludge process and a 6 MGD standard-rate trickling filter process. These units operate in parallel to give a total plant capacity of 18 MGD. Although this plant is quite large for preliminary studies, at the time it was the only activated sludge plant located within a reasonable distance.

#### Macon Treatment Plant

The sewage treatment plant of the City of Macon, Georgia is located south of the city near the Ocmulgee River. It was designed for a flow of 12 MGD and was placed in operation in 1959. Present flow is 10-12 MGD in dry weather and as much as 20 MGD in wet weather. Major units of plant equipment are as follows: bar screen and grit chamber, raw sewage pumps, 4-compartment primary basin, two high rate 170' diameter trickling filters, 4-compartment clarifier, and chlorination facilities. Step digestion is used and the plant is equipped with two 90' diameter and three 75' diameter anaerobic digestors.

#### Marsh Creek Plant

The Marsh Creek Water Pollution Control Plant is a 0.75 MGD secondary treatment plant located in north Fulton County. It consists of the following basic units: screen and grit facilities, raw sewage pumping station, two 49' x 10' rectangular primary settling tanks, one 77' diameter high rate trickling filter, two 40' x 10' rectangular secondary settling tanks, one 40' diameter sludge digester, three sludge

drying beds, effluent chlorine facilities, and administrative facilities. The sludge digester is equipped with a Perth unit which provides more thorough mixing than the customary system of pumps.

#### Snapfinger Creek Plant

The Snapfinger Creek Water Pollution Control Plant of DeKalb County, Georgia is located on South River, near its confluence with Snapfinger Creek. The original design capacity of this facility was 6 MGD, but was increased to about 8 MGD by addition of temporary combination units which provide activated sludge, secondary clarification, and aerobic digestion. The plant is heavily overloaded and is receiving 13-17 MGD. Additional facilities are under construction. The original major plant units include 60' x 85' diameter primary and secondary settling basins, a 165' diameter trickling filter, two anaerobic digestors, and drying beds.

#### Douglas Treatment Plant

The Douglas Water Pollution Control Plant is located on Seventeen Mile Creek in Coffee County, in the outskirts of Douglas, Georgia. The plant was designed for a capacity of 2 MGD but is now receiving approximately 4 MGD. The plant equipment includes two primary tanks, a 50' diameter high rate roughing filter, two 102' standard rate trickling filters, two secondary clarifiers, two anaerobic digestors, and drying beds.

### DETAILS OF PLANT TESTS

#### Measurement of Flow Time in Sewer--Bromine and Dye Tracers

The initial field test was a measurement of the time of flow through a sewer into the Sandy Creek Plant. In many instances, flow measurements can be easily made by visual observation of a dye marker, but this technique does not readily give quantitative information, and is not applicable to highly colored wastes or to turbid streams that obscure the added color. For convenience and purposes of comparison, a rhodamine dye was added to the stream at the same time as the stable tracer in this test. The flow measured was domestic sewage and did not interfere with the added dye marker.



In consultation with the plant superintendent, a manhole was selected for introduction of the tracer solution. Measurements taken from a cadastral map showed the distance to be about 6400 feet and the superintendent estimated time of flow from the manhole to the treatment plant at about 20-30 minutes.

At 2:19 PM, a gallon of solution containing 600 grams of sodium bromide and 200 ml of Rhodamine WT was introduced into the system at the selected point. Five minutes later a gallon of water containing 450 grams of Rhodamine 6B was introduced. Rhodamine WT is a fluorescent dye and reportedly can be detected by a sensitive fluorometer at the parts per billion level. It was expected that this material would not be visible to the eye, but would be detected by a fluorometer so that sampling could be started. Rhodamine 6B was added to evaluate its use as a visual indicator. A continuous-flow recording fluorometer was therefore positioned at the grit chamber, and sewage was pumped through the fluorometer by a small submersible pump.

At 3:08 PM the fluorometer indicated the arrival of a fluorescent material and the previously initiated sampling interval was reduced from five minutes to one minute. Sampling was continued until 3:30 at which time the fluorometer readings had returned to their background level.

The highly visible Rhodamine 6B did not appear until 3:37 PM; 29 minutes after the first tracer, although there was only a five minute interval between the introduction of the two tracers. The flow of sewage during the entire period of the experiment was reasonably constant, and there is no obvious explanation for the longer time required for the second material to travel the same distance as the first.

One-ml portions of the samples were pipetted into numbered irradiation vials and returned to the laboratory for analysis by neutron activation. The sample vials were heat sealed, irradiated in the Georgia Tech Research Reactor for 5 minutes, and counted about 2 hours later. Bromine was detected at levels up to 0.6 ppm in nine of 22 samples collected. These erratic results were due to the low peak-to-background ratio resulting from the presence of only small amounts of bromine. Longer irradiation periods would have improved the counting statistics, but for reasonably accurate results at practical irradiation times, the bromine content



should be increased by an order of magnitude. It was therefore considered that other tracers would be preferable for such uses.

The fluorometer is a very sensitive instrument and under ideal conditions would be capable of giving precise results. However, under the field conditions encountered, it proved unsatisfactory. The instrument itself is heavy and requires two men to handle it. It operates on alternating current and requires the use of a portable generator at points where electricity is not available. The bits of paper, rags, and other solid matter in the sewage effectively clogged the intake of the submersible pump so that it was necessary to stop and clean it every 2 or 3 minutes. Only invalid data could be obtained while the pump was not operating. A more fundamental difficulty was the instability of the instrument. Background readings drifted over a range of 2-3% of the scale and created serious doubt as to the precision of the readings at any given time. Because of the inconvenience of this method of tracer detection its use was discontinued and Rhodine 6B was used as a visible marker in all subsequent tests.

#### Activated Sludge

An experiment intended to reveal information on flow conditions in an activated sludge tank was carried out at the South River WPC Plant. At the time of the study, the rate of flow through the tank into which the tracer was injected was approximately 5 MGD which included 1 MGD of return sludge. The placement of the air diffusers in this tank produces a rolling motion in the liquid, and a given particle presumably moves in a spiral fashion from the inlet to the outlet of the tank. The theoretical detention time is about  $2\frac{1}{2}$  hours and the suspended solids in this system average about 2300 mg/l. The tracer solution contained 25 grams of indium, as well as 400 grams of Rhodine 6B to serve as a visual indicator. After the tracer solution was poured into the tank, the dye marker was rapidly obscured and only a slight tinge of color remained after two minutes.

It had been anticipated that visual marking would require rather large amounts of dye, but following this experience it is believed that as much as 20 pounds would be needed to assure continued visibility throughout the tank. Due to the lengthy detention time and the lack of any visual indication as to the location of the tracer front, samples were collected

at locations one fourth and one half the length of the tank from the inlet.

It was thought that the vigorous motion of the tank contents would produce a large amount of mixing and concomitantly a high dilution of the added tracer. Referring to Figure 2, it will be seen that longitudinal mixing occurred so that the initial concentration of 63 ppb decreased for 35 minutes at which time a very high peak (130 ppb) appeared. The indium level decreased gradually thereafter with a small, presumably insignificant, fluctuation near the two hour time. At the half-way station, a similar pattern was noted. The maximum concentration there was only 70 ppb and occurred 15 minutes after the maximum at the quarter location.

Two vials were filled from the sampler at each time interval, and agreement between the two portions was less satisfactory than for other experiments. The lack of consistency may have been due to variations caused by the rapidly-settling solids present. It is believed that most of the tracer was absorbed by the solids present, and any difference in the amount of solids transferred to duplicate vials would cause large differences in the observed results.

#### Trickling Filter Studies

The Flint River Sewage Treatment Plant of the Clayton County Water Authority had been having difficulty for some time with their trickling filter. Ponding was evident, but more importantly, the BOD reduction across this filter was essentially zero. Gas production of both digesters was far below normal levels and a common cause of these difficulties was suspected. A consulting engineer was called in to assist in solving the problems.

Permission was readily obtained from those in charge for tracer studies to be carried out at any points desired within the plant. This provided an opportunity for comparison of the flow pattern through a badly clogged filter with the normal pattern to be obtained at a later date after the filter had been restored to normal operation.

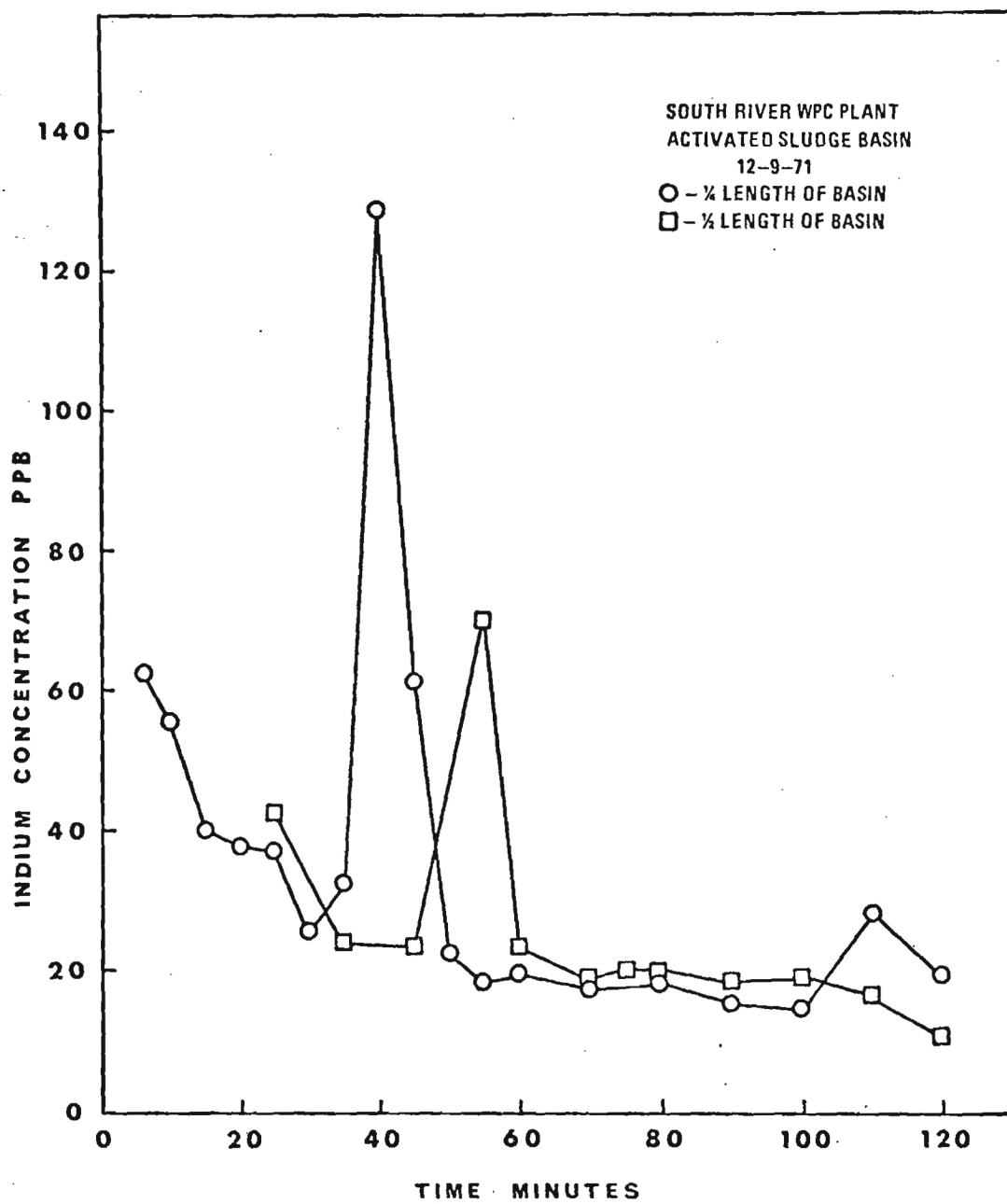


Figure 2. Tracer Concentration at Two Points in South River WPC Plant Activated Sludge Basin

The initial test was carried out on June 1, 1971, at which time severe ponding was evident. It was observed that the ponded fluid seemed to drain into a few specific crevices rather than to spread evenly and quickly into all the openings between the stones which compose the filter. From this it was concluded that flow was occurring through a few channels and no appreciable amount of liquid was reaching a major part of the filter. On digging into the filter, it was found that most of the interstices of the stones were filled with a dense gelatinous mass, later shown to be primarily aluminum oxide-hydroxide. The aluminum came from an upstream industrial plant and in time resulted in the plugged filter. With most of the filter plugged and the balance continuously flooded, no bacterial action resulting in appreciable BOD reduction could occur.

The tracer tests were carried out using indium as the activable material plus Rhodine 6B for visual observation. The tracer solution was poured into the dosing box of the filter and samples were collected at the filter outlet and at the center (inlet) and rim (outlet) of both secondary clarifiers. The results of the first test are shown in Figure 3. The curve labeled "A" represents the concentration of tracer at the filter outlet, which is about eight feet below grade level. The flow at this point was apparently not very well mixed as the dye tracer was more concentrated at the center of the stream of effluent. More thorough mixing occurs in the downstream pipes which divide and deliver the liquid to the center of the secondary clarifiers. If the flow were completely mixed, the maximum concentration would be the same at the filter outlet and the clarifier inlets.

Two samples were lost due to a faulty pipette and experimental points between 5 and 10 minutes for curve "C" are missing. Judging from the slopes produced by the other points, the maximum point for curve "C" would have been comparable to that of curve "B". This supposition is supported by the results of the later test. The maximum in curve "C" occurred after the maximum in curve "B", because the pipe which supplies sampling point C is longer than that supply point B.

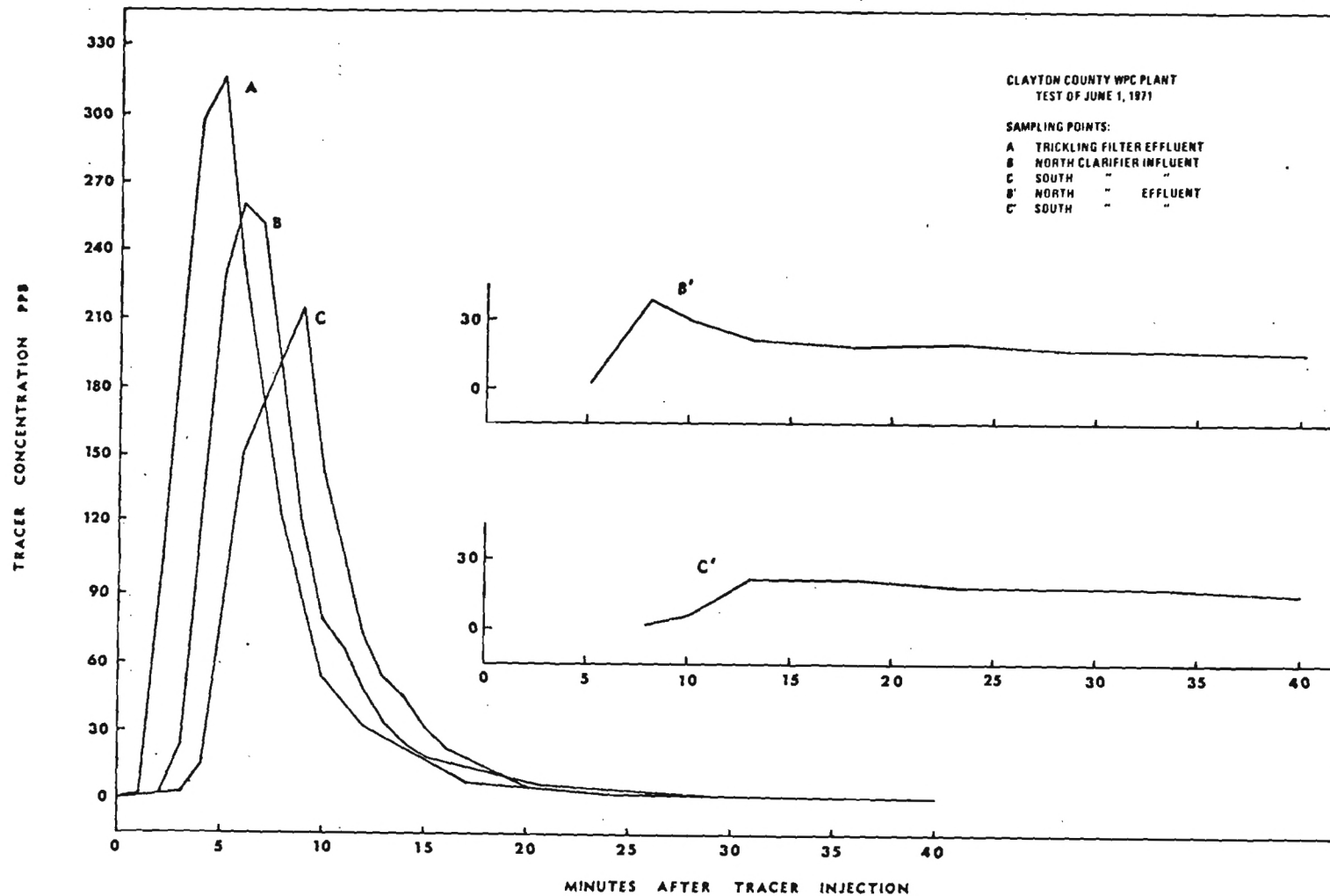


Figure 3. Tracer Concentration at Various Points in the Clayton County WPC Plant, June 1, 1971

The north clarifier has a diameter of 36' and showed a tracer peak at the outlet at about 8 minutes. This very rapid traversal of a basin that should have a much greater detention time is due in part to a faulty arrangement of the basin inlet. The inlet has a metal baffle around it, apparently intended to prevent rapid movement across the surface. The upper edge of this baffle was submerged, however, due to the higher elevation of the outlet (rim) weir. As soon as dye became visible in this tank, streaks of color moved promptly to the outlet. The indium levels were in accord with the observed color and decreased as time went by and better mixing occurred. Because of the mixing, a very long time would be required to dilute the tracer to below the detection level.

The south clarifier has a 52' diameter, and the inlet baffle is above the surface of the water. The tracer concentration at the outlet, therefore, did not peak sharply, but rose to a maximum and decreased very slowly during the remainder of the experiment.

Following this test the consulting engineers had the filter washed with several thousand gallons of 50% caustic soda solution, a treatment which only partially removed the accumulated solid matter. The filter stone was then removed, washed with fire hoses, and replaced. The engineering details of the cleaning and other operational aspects of this problem have been published (7).

After the cleaning of the filter was complete, a period of several weeks was required for the reestablishment of normal biological conditions. On August 24, 1971 a second tracer experiment was performed using the same injection and sampling points as before. The results of the analysis of the collected samples are shown in Figure 4. In this case the maximum concentrations at points A, B, and C were all about the same, which indicates that perhaps the fluid moving through the filter was more thoroughly mixed. It is important to note, however, that the maximum value at each point was recorded at the same time as when the filter was clogged. This finding indicates that the hydraulic situation was essentially identical whether or not the filter was clogged. Although the exact outcome of this pair of experiments had not been predicted, differences were anticipated. These results have considerable theoretical



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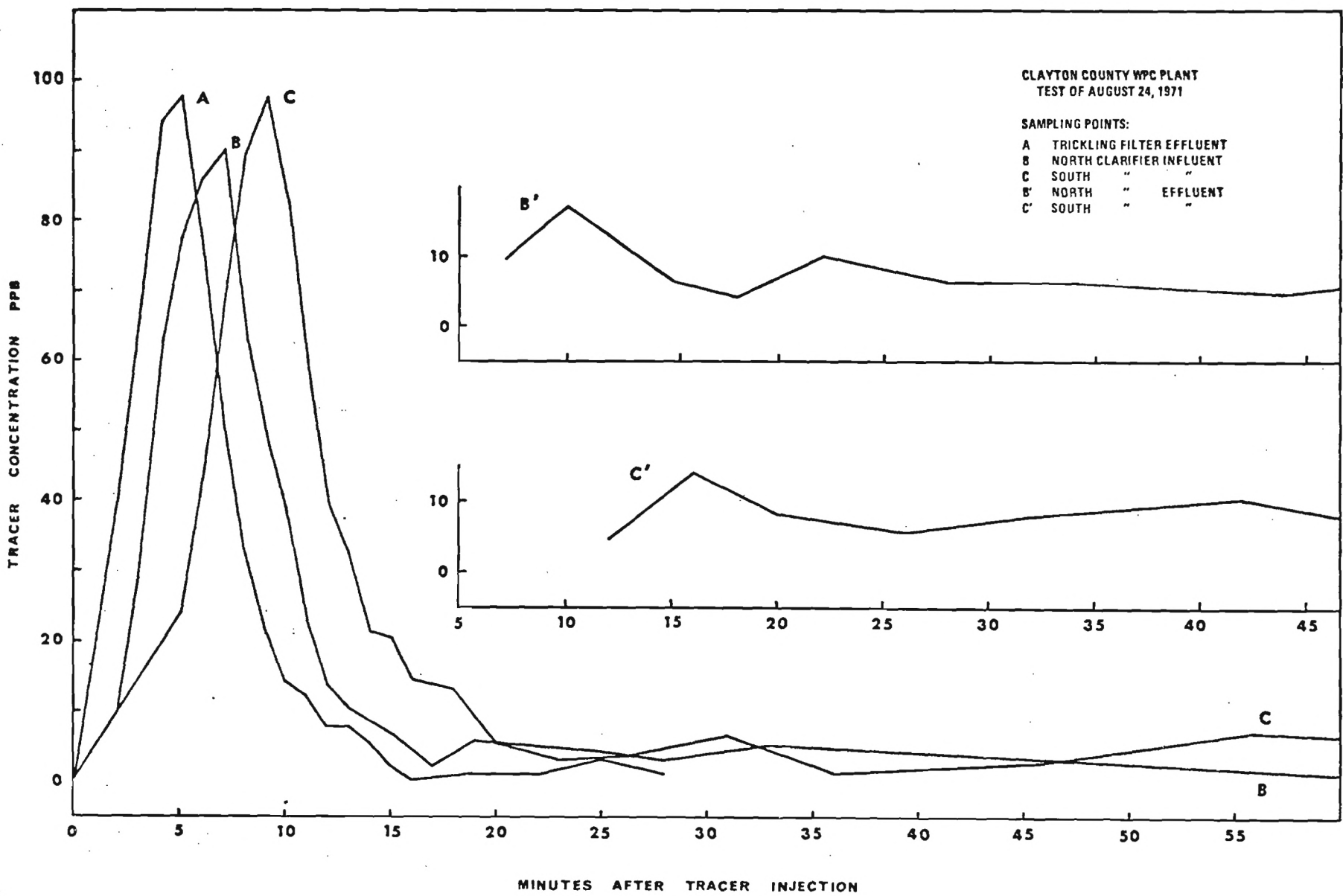


Figure 4. Tracer Concentration at Various Points in the Clayton County WPC Plant, August 24, 1971

implications on the measurement and significance of retention time in trickling filters (7).

In another test, a trickling filter at the old Flint River WPC Plant of the City of Atlanta was studied to provide a comparison with the one at the Clayton County plant. Indium tracer plus Rhodine 6B was introduced into the dosing box of one of the two filters at the plant. Samples taken at the filter outlet produced the curve labeled "A" in Figure 5. Curves B and C represent concentrations at the inlets to the two halves of the divided secondary clarifier. The maximum values at these points are much lower than at the filter outlet because the flow is combined with that of a second trickling filter.

The time of flow from the filters to the clarifier was short and the maximum tracer concentrations occurred almost simultaneously. Curves B' and C' were obtained from samples taken at the outlets of the clarifier and reveal considerable difference in the behavior of the two halves. On the B' side, the tracer concentration began at a low value, increased slowly, and then decreased. This indicates that considerable mixing had taken place in contrast to the situation on the C' side where the tracer moved as a compact slug, beginning at a high value persisting for several minutes and then decreasing rather quickly to a lower continuing value.

According to the plant superintendent, this basin was designed for a two hour detention time, and the appearance of the dye tracer in the outlet after only 45 minutes came as a surprise. The pattern observed on the C' side is clearly indicative of short circuiting and may have been related to the presence of a heavy scum layer covering most of this side. In neither side of the basin was the dye visible except near the inlet and at the outlet. This disappearance of the dye near the inlet indicates a density differential so that the colder influent sinks, moves across the bottom of the tank, and rises to the outlet at the effluent end of the tank. It was concluded from this experiment that short circuiting was actually occurring in both sides of the basin.

#### Sludge Settling

At the outlet of the sedimentation basin of the Sandy Creek WPC Plant, particulate matter was observed passing over the weir and to the plant

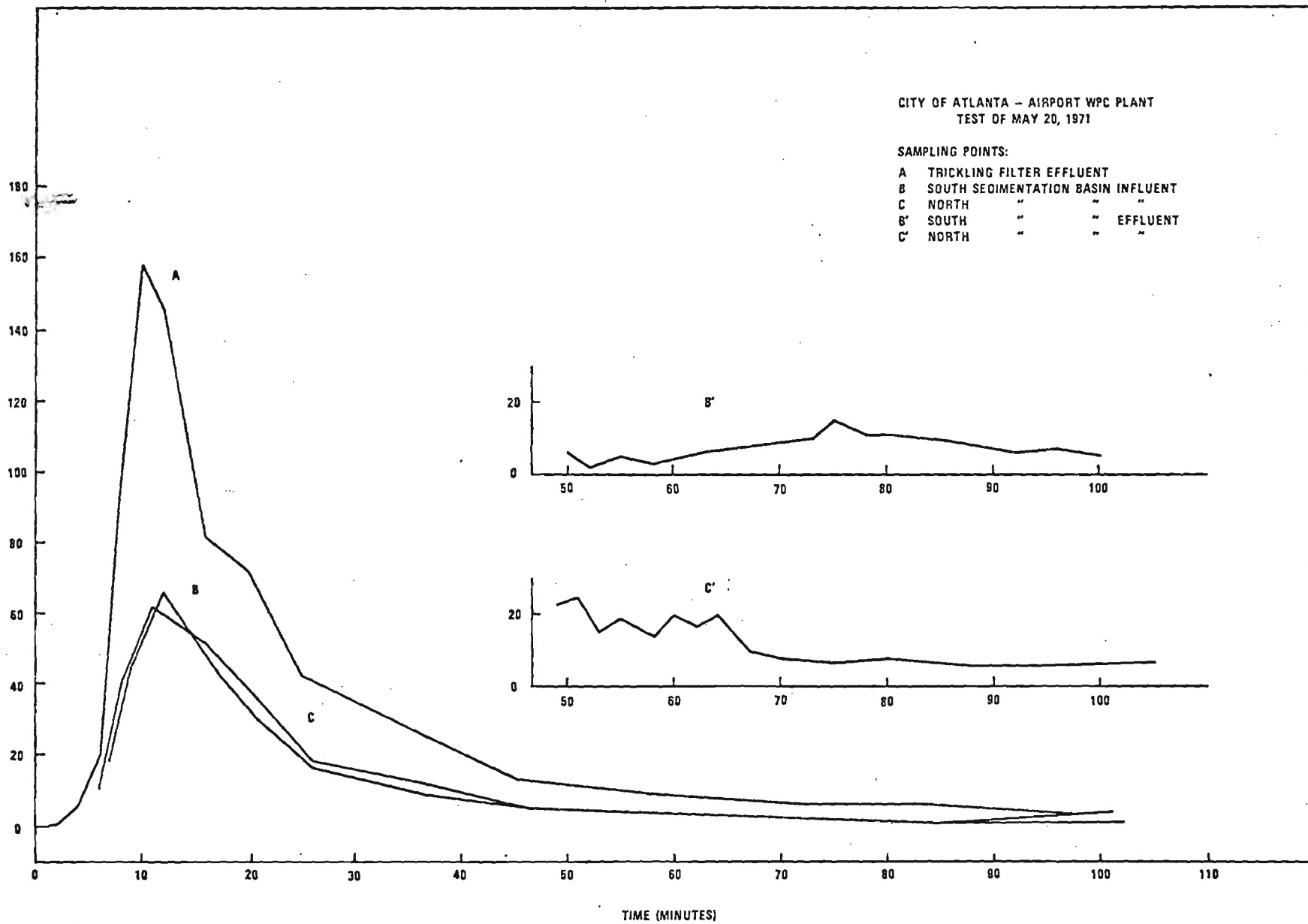


Figure 5. Tracer Concentrations at Points in Atlanta Flint River WPC Plant

outfall. In order to study this situation more fully, sludge was labeled with a tracer and the concentration in the effluent measured as a function of time.

Approximately three gallons of sludge were collected from the sump at the sedimentation basin and placed in a five gallon can. Ten grams of indium (as the sulfate) dissolved in a little water were added, and the mixture was heated almost to boiling over a portable propane furnace. The mixture was stirred during the half hour heating period. The hot sludge was then poured into the inlet of the east side of the sedimentation basin and this was followed by a gallon of water containing 200 grams of Rhodine 6B. Color appeared in the effluent at 24 minutes and sampling was begun. Quart samples were obtained at 3 minute intervals. At 2 minute intervals, duplicate 1 ml samples were collected. No dye color was evident anywhere in the basin except at the outlet and sampling was continued until the color of the effluent had faded to a low level.

Upon return to the laboratory, the quart samples were filtered by suction and the solid matter collected and analyzed. Samples of the filtrate were also analyzed and found to contain indium, although at a much lower concentration than the solids. The results of these analyses are shown in Figure 6. The concentration of tracer in the sludge is seen to fluctuate in a very regular periodic fashion. Concentrations of tracer in the supernatant also fluctuated in a very similar fashion although not exactly in phase with those of the sludge.

This pattern of behavior is indicative of a pattern of recirculation, with a period of nine minutes. There was nothing about this basin that accounted directly for these results. The sludge scraping mechanism moves very slowly and continuously and does not seem capable of producing this pattern. This possibility is not to be discounted entirely, however, as the lack of dye color in the basin indicated a density current. It is possible that this current produced a rolling motion as it impinged upon the outlet wall of the basin. Part of the flow would exit over the weir and the balance would roll back toward the basin inlet. Each time this mass of water rotated, the tracer concentration would be lessened by the amount previously lost, and by dilution.

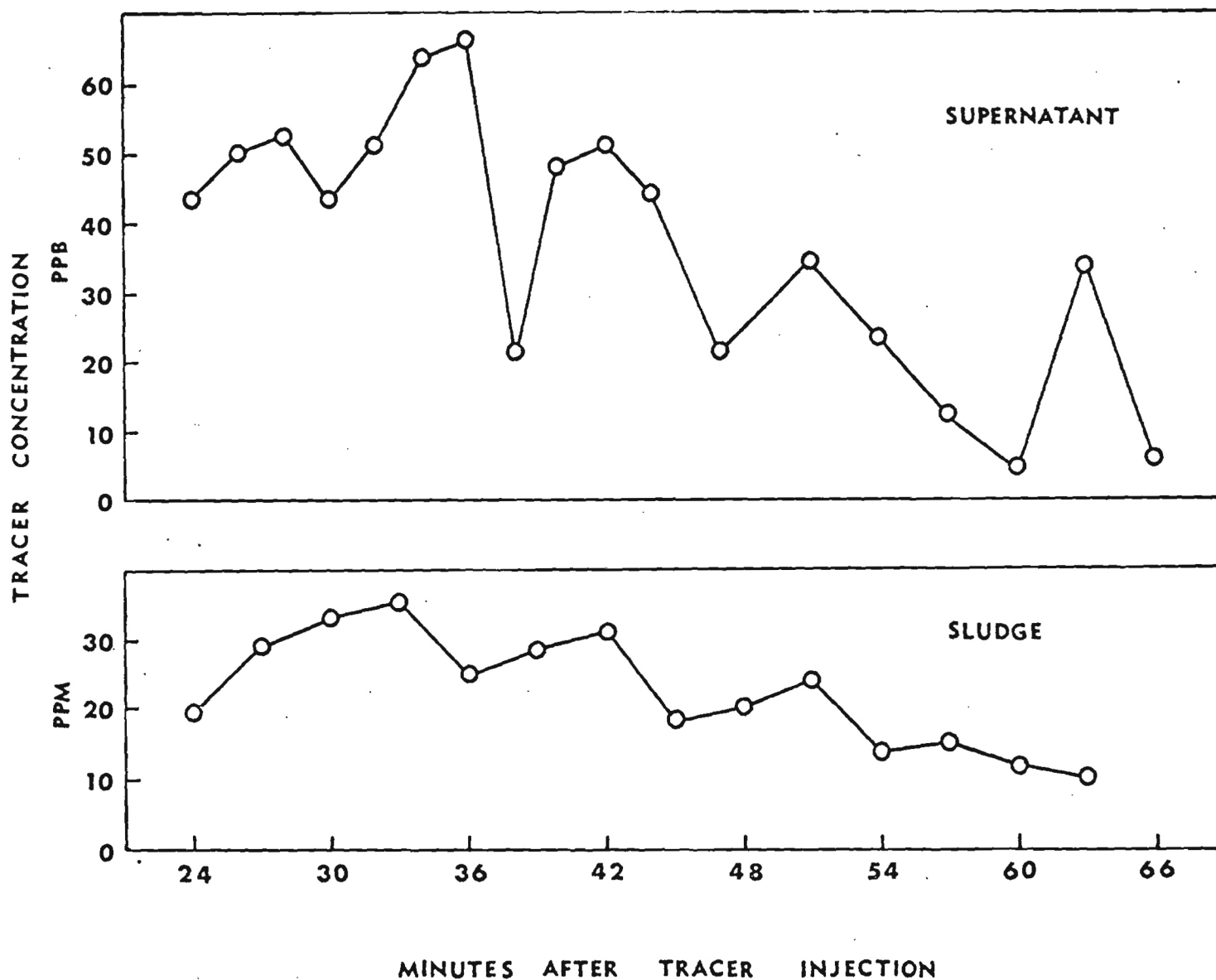


Figure 6. Indium Concentration in Sludge and Supernatant--First Test

In an attempt to clarify this situation, the experiment was repeated, the only differences being that indium solution was stirred into the sludge without heating and samples were collected at one minute intervals. The results of this second run are shown in Figure 7, where it is seen that the pattern is entirely different from that of the first test. At the time of the second run, the recirculation pattern was absent and tracer concentrations rose to a rather ill-defined maximum and then gradually decreased.

As other conditions about the basin appeared to be the same as previously, the maximum tracer concentrations of the two runs are taken as some indication of the efficiency of solids collection. The second situation when the indium maximum was only about 12 ppm is taken to indicate better operation of the basin than in the first test where tracer concentration went above 30 ppm.

#### Sedimentation Tank Study at the New Flint River Plant

At the new Flint River Plant activated sludge process functioned quite well until late 1972 when bulking began to occur. Typically trouble commenced about noon when large amounts of suspended matter began to pass over the outlet weir of the secondary clarifier. This condition sometimes changed during the early morning hours, so that normal operation could be achieved for several hours before noon. During other periods, bulking occurred continuously.

The cause of the problem had not been determined at the time of test, although it was later shown to be due to the toxicity of heavy metal plating wastes in the influent. Changes in the flow rates, air injection rates, and other variables were tried, but were not effective. It appeared that a tracer test to determine flow patterns in the secondary clarifier might be helpful, and was therefore carried out.

The clarifier basin is square, and the outlet weir is also square and situated about three feet from the basin walls. The basin inlet is in the center, and a submerged drum introduces the influent about six feet below the liquid surface. A shallow circular barrier confines floating matter which is collected by a skimmer rotating about the center structure.



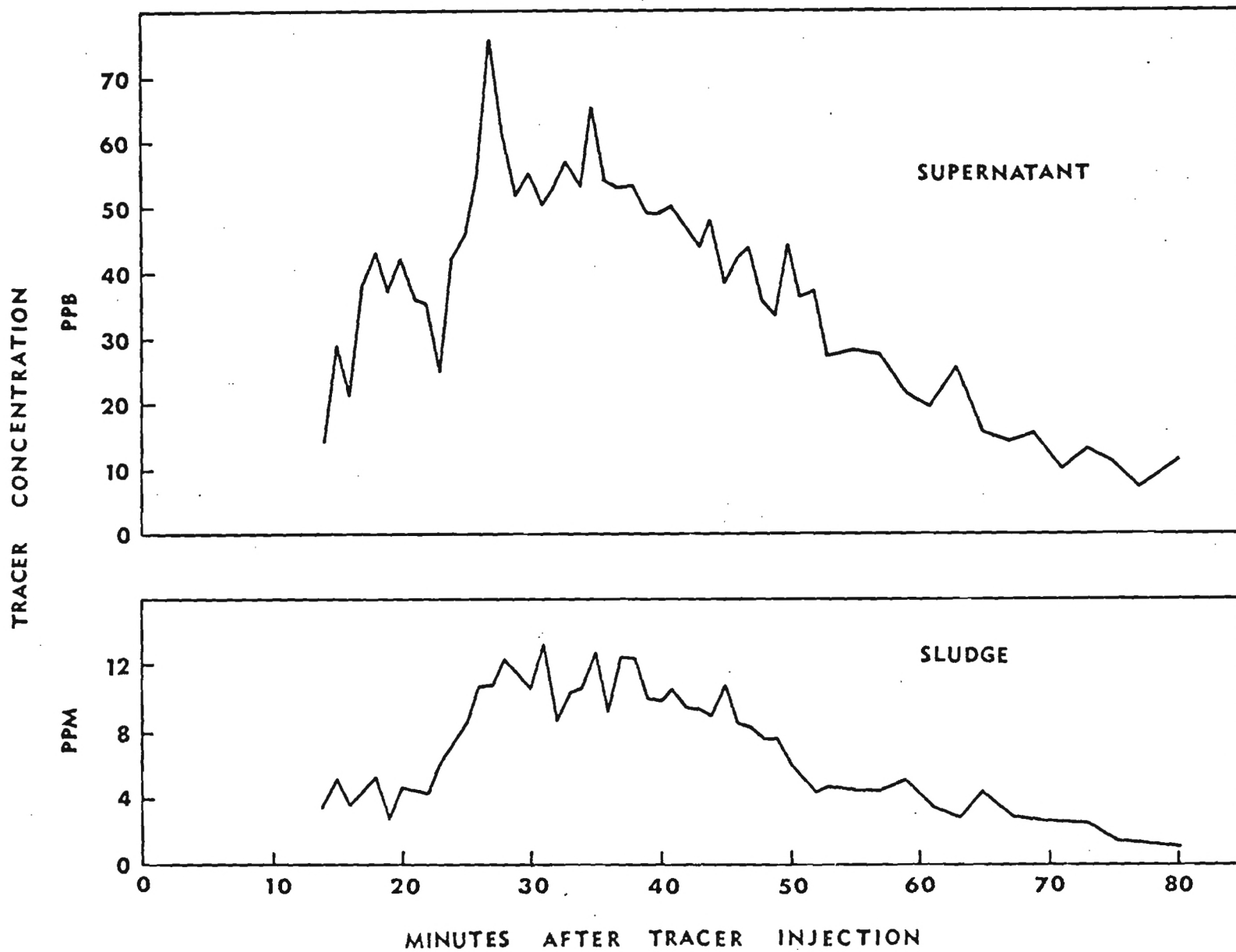


Figure 7. Indium Concentration in Sludge and Supernatant--Second Test

It was noted that when bulking commences, more solids enter the weir trough from the side adjacent to the basin wall. It is assumed that this is because solids moving toward the wall are deflected upward and back toward the center of the basin. Samples were collected on both sides of the weir trough at three different locations around the periphery of the basin.

It was calculated that at a flow rate of 2.5 MGD, the average detention time should be on the order of 4 hours, but a preliminary trial using dye revealed color in the outlet in less than 30 minutes. For the actual test, indium was used as the tracer, and dye was used as a visual indicator. Samples were collected, analyzed by neutron activation, and the results plotted as shown in Figures 8-10. Figure 8 shows that the concentrations of tracer are essentially identical in the flows from each side of the trough at the southeast corner of the basin. It was at this position that color appeared last, and the tracer concentration curve was similar to those of other basins. The shape of this curve is probably due to the movement of some tracer across the surface of the basin; this produced a small early peak. Somewhat later a more concentrated surge occurred, and this was followed by flow in which the tracer was more evenly dispersed. It seems clear that the patterns of fluid movement within the basin are not uniform around the basin, as different results were obtained at other sampling points.

Figure 9 shows the results obtained on one side of the catwalk which provides access to the center of the basin. For a short time there was a difference between the two sides of the trough, with concentrations considerably higher on the inner side. This was due to a highly visible streak of dye and tracer which was forced across the surface of the liquid by movement of the skimmer. The data of Figure 10 were obtained from the opposite side of the catwalk, but the skimmings outlet structure obstructed the tracer flow across the surface and concentrations on both sides of the trough were about the same throughout the test.

There are appreciable differences between Figures 9 and 10 although their general appearances are similar. The high values noted early in the test period may be explained on the basis of a short circuit that

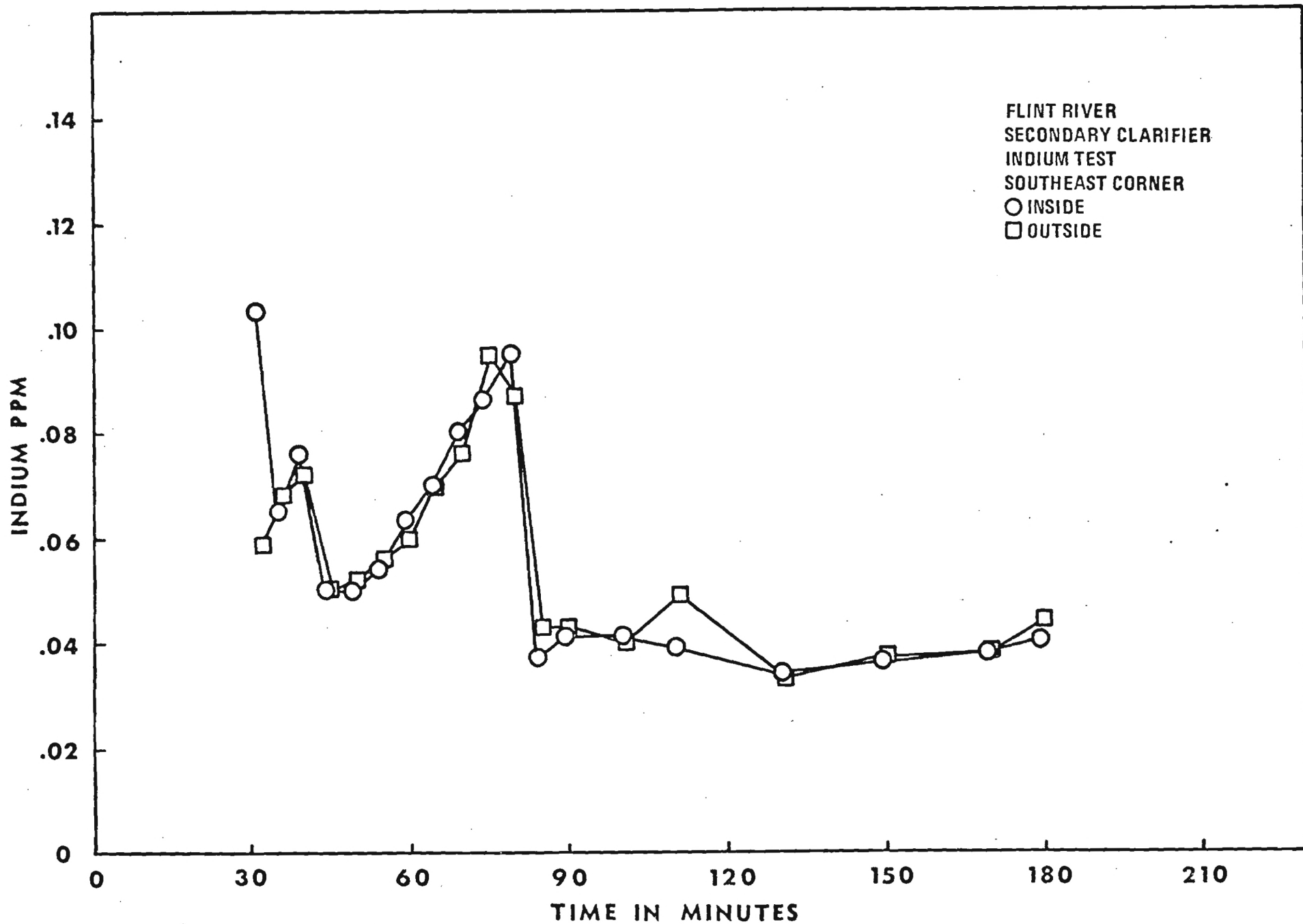
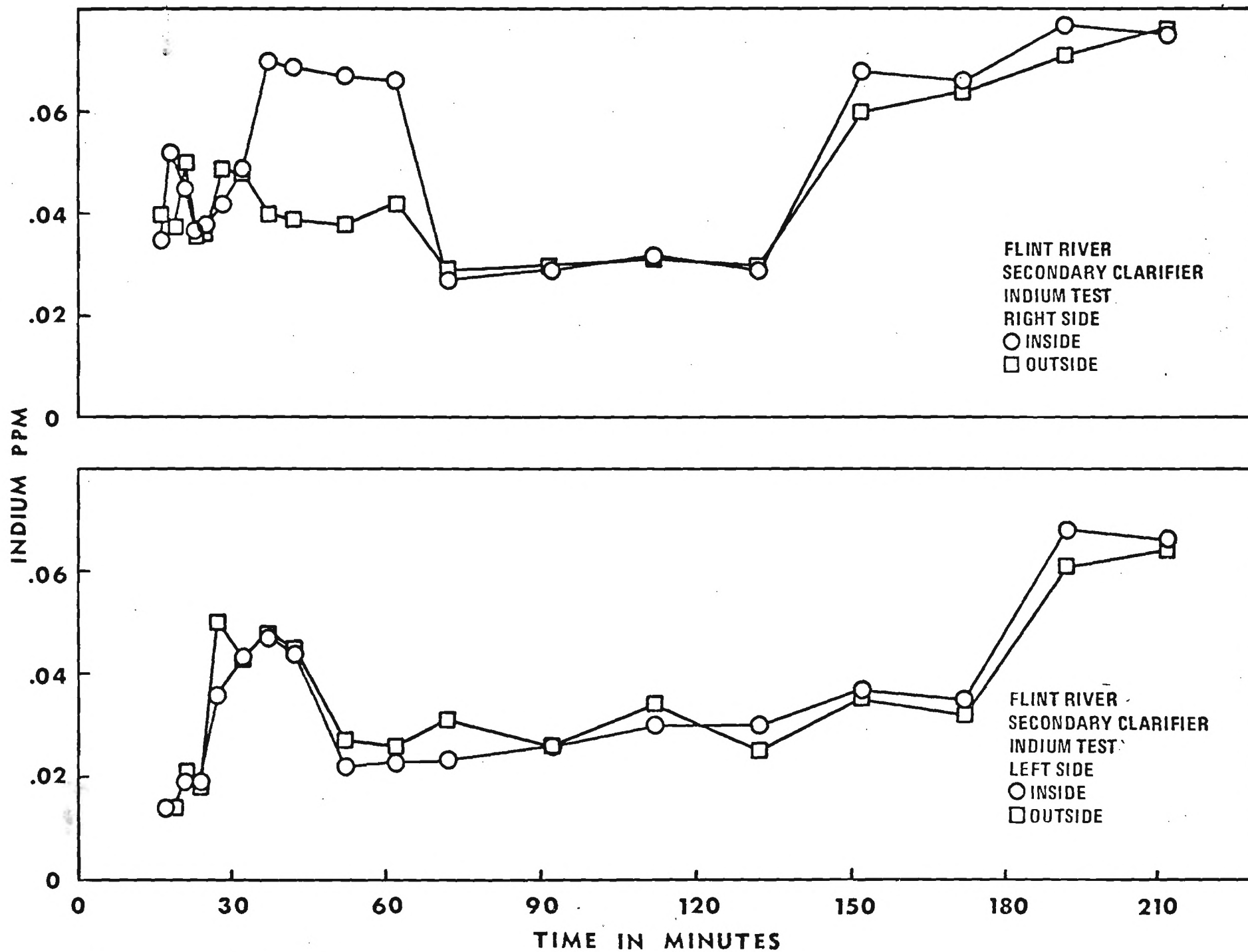


Figure 8. Sedimentation Tank Study - Trough Samples



Figures 9 and 10. Sedimentation Tank Study

involved a small portion of the total flow. Only a small fraction of the tracer would be required to yield high concentrations in a small direct stream flowing across the basin surface. The balance of the flow is believed to remain in the basin for a longer period of time, and high values were also observed at the end of the test period. The main portion of the tracer, diluted by the major flow, produced these latter high readings.

The shape of the curves in Figures 8-10 and the fact that they are all different, indicates the complexity and non-uniformity of the flow pattern. Although identical behavior between the sides and corners of a center-fed square basin would not be expected, similarity would be more easily explained. The consulting engineers attempted to determine the sludge level in the basin at various times by drawing samples from different depths, but the lack of a sharp boundary led only to indefinite results. It was concluded from this study that at least a portion of the flow through this basin was short-circuited, but this was not considered the major cause of the bulking problem. It seemed that the condition of the sludge was largely to blame, and probably it would not have settled very effectively even under optimum conditions for sedimentation.

The results obtained from this test were compared with those of a somewhat similar test carried out in this basin before the bulking problem began. In the earlier test, manganese was used as the tracer element and was deposited as manganese dioxide on sludge particles by mixing potassium permanganate and manganous sulfate in stoichiometric proportions in the presence of settled sludge.

The labeled sludge was poured into the basin inlet and quart samples were collected at the basin outlet. Each sample was filtered and the solids and supernatant were analyzed separately. The results of these analyses are shown in Figures 11 and 12. Time zero on these plots is the time at which sample collection was begun. Concentrations of manganese in the supernatant fluctuated widely and no specific conclusions could be reached, other than to note that the manganese concentration was well above the background level of less than one part per million. There was less fluctuation in the tracer concentration on the sludge. The general behavior was a rapid increase for about 30 minutes, followed by

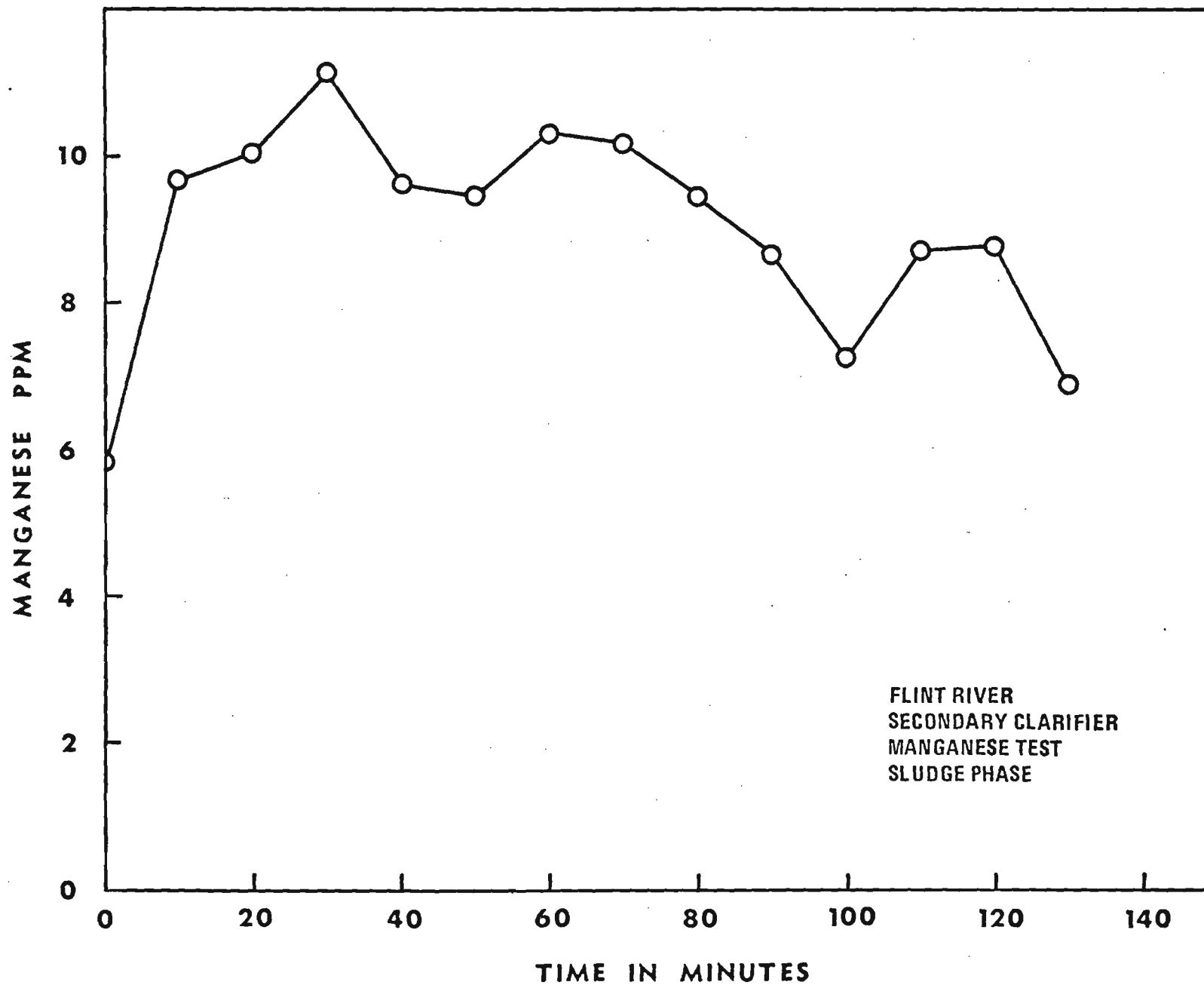


Figure 11. Manganese Tracer Test - Solids Samples



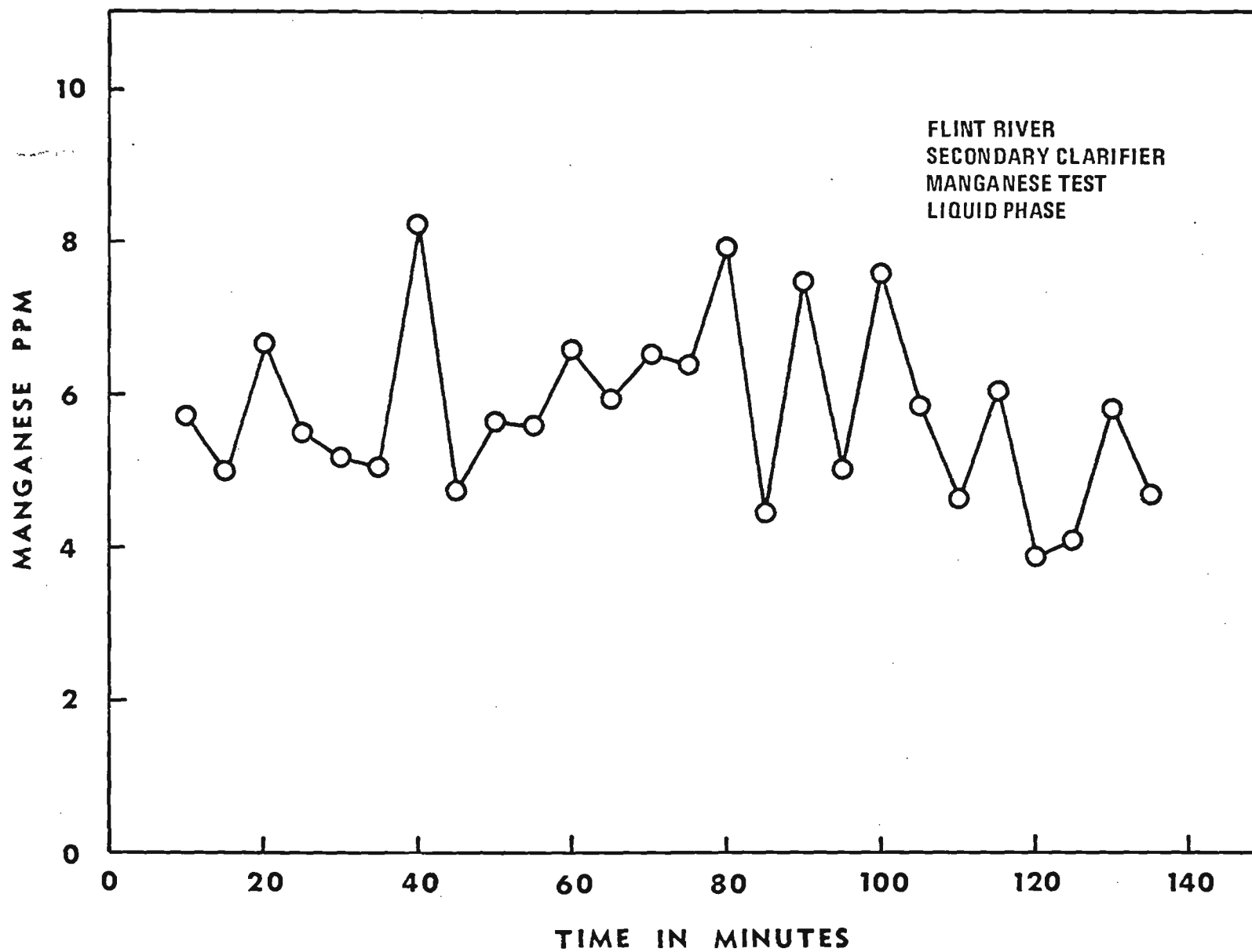


Figure 12. Manganese Tracer Test - Supernatant Samples

a gradual downward trend. These findings are considered too erratic for any specific conclusions to be drawn, but at the time of the test the basin was operating in an acceptable manner, and tracer did not appear in the effluent until 50 minutes after it had been added to the influent.

#### Snapfinger Creek Flow Study

One of the two temporary combination treatment units at the Snapfinger Creek Plant was not functioning properly. A large amount of brown froth was being produced and the effluent was not as clear as normal. This offered an ideal situation in which to compare flow patterns simultaneously in two large identical units receiving influent from the same line.

A tracer solution consisting of 50 grams of indium dissolved in nitric acid and 500 grams of Rhodine 6B was introduced into the inlet of each tank, and samples were collected at the tank outlets. The samples were analyzed and the results plotted as shown in Figure 13.

Tracer reached the outlets of both tanks very rapidly, but higher early values were observed in samples from the poorly performing tank. The general level of tracer concentration from this tank remained at about the same level throughout the test. Samples from the normal tank showed steadily increasing values for about an hour and a half. The difference in these trends may be explained on the basis of differences in the flow regimes involved. The high continuing values indicate a completely mixed situation which is not desirable in sedimentation as it does not allow suspended solids to settle out. This conclusion is consistent with the observed poor sedimentation being achieved in this tank.

In the normal tank, the gradual increase in tracer indicates less thorough mixing of the influent with the tank contents. Although this is not strictly plug flow, it is a modified plug flow regime in which increments of liquid leave the basin in the general sequence in which they enter. In complete mixing, labeled liquid volumes lose their identity and the tracer concentration decreases exponentially.

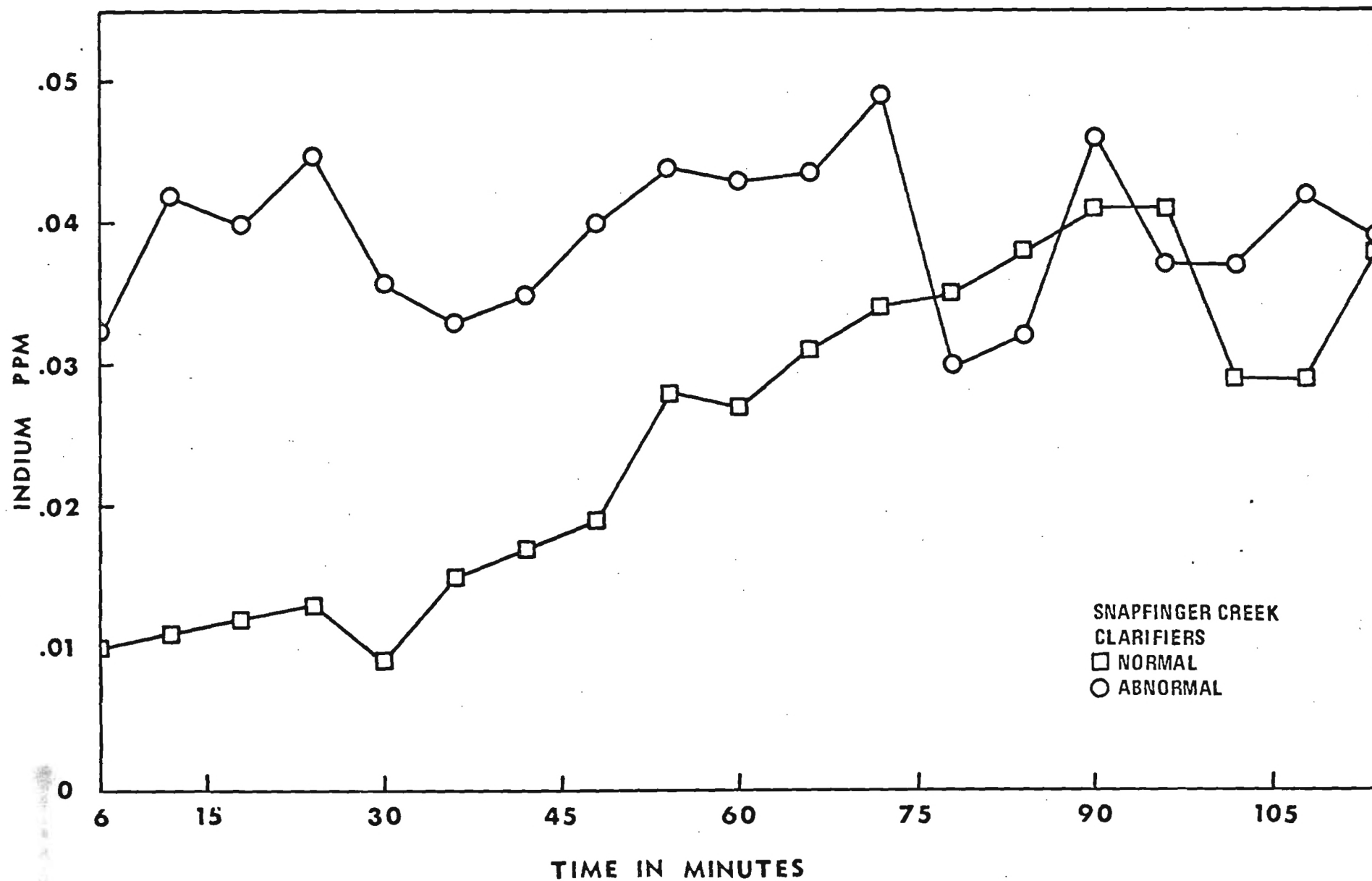


Figure 13. Tracer Test - Snapfinger Creek Plant

It is therefore concluded that the difficulty encountered in the treatment process was due to a flow regime inappropriate for the results sought. The cause of this difference was never discovered. It began when the unit was placed in operation and disappeared gradually after several weeks. There were no obvious differences in the construction of the two units and they received flow from the same influent line. Four more units identical to the first two are now under construction, and they will be carefully watched as they are successively put into operation to see if this transitory phenomenon occurs again.

#### Radioactive Tracer Test

To compare the relative utility of radioactive tracers and stable tracers, an experiment using the 15-hour radioisotope sodium-24 was performed at the Sandy Creek WPC Plant. Extensive planning was required, as it was necessary to obtain permission to use a radioisotope for this purpose from the Radiation Protection Committee of Georgia Tech, the waste treatment authorities of the City of Atlanta, and the Georgia State Health Department. After agreement of all parties concerned had been obtained, the radioisotope was prepared by irradiation of sodium carbonate in the Georgia Tech Research Reactor. The dry power was placed in a closed but unsealed polyethylene vial and irradiated for a period of time calculated to produce approximately 150 millicuries of activity. Gross activity measurements of the irradiated vial showed that slightly more activity was produced than had been calculated.

The vial containing the isotope was placed in a lead shield, placed in an approved shipping container, and transported to the plant site in a truck bearing "Radioactive" placards. This truck was driven by a staff member of the Georgia Tech Office of Radiological Safety who also monitored subsequent operations in the field. All personnel connected with the work wore film badges or thermoluminescent dosimeters. No reportable exposures ( $> 40$  mR) were incurred.

The radioisotope was prepared for use by submerging the irradiation vial in water contained in a one-gallon wide-mouth plastic jar. The vial was squeezed with long-handled tongs, and this forced off the lid of the vial. It was emptied and rinsed in the water. The tongs were then used

to pour the active solution into the inlet of the sedimentation basin. A solution of Rhodine 6B was poured simultaneously into the inlet of the east side of the basin.

This sedimentation basin is divided so tracer moved through only one side. The flow is recombined at the basin outlet, so the radioisotope concentration was reduced to one half by dilution prior to release to the river.

Field instrumentation for this experiment consisted of a sodium iodide scintillation detector with a scaler. The scintillator probe was wrapped in several layers of plastic and was positioned in one of the troughs of the outlet weir, where it was submerged to a depth of one or two inches. Also utilized on site was a sodium iodide scintillation detector connected to a single channel analyzer. The crystal was located in a lead shield and 10-ml samples in polystyrene vials with polyethylene caps were counted in a 5 volt window about the 1368.4 keV sodium photopeak.

The immersed scintillation detector was much too sensitive for the selected geometry, and the lower sensitivity settings of the scaler were later found to be difficult to correlate. The majority of the readings were taken at the same setting, however, so that most of the results are self-consistent. With the exception of a couple of points, the readings agreed quite well with the results obtained from the single channel analyzer. The results of both methods of analysis are plotted on the graph of Figure 14.

The samples were returned to the laboratory and on the following day were counted on the semiconductor detector and gamma-ray spectrometer system regularly used in the neutron activation work. Additionally, the entire spectrum of the samples was counted on a scintillation detector. Findings of the latter determinations are detailed in Figure 15.

It will be noted that on all of these curves the concentration was decreasing rapidly in the period of 30 to 40 minutes following tracer injection. At 42 minutes, the sludge scraping mechanism was turned on, and the pattern of concentrations changed. The rate of decrease lessened and was fairly constant during the last 20 minutes of the experiment. These findings justify the belief that operation of the sludge scraper,

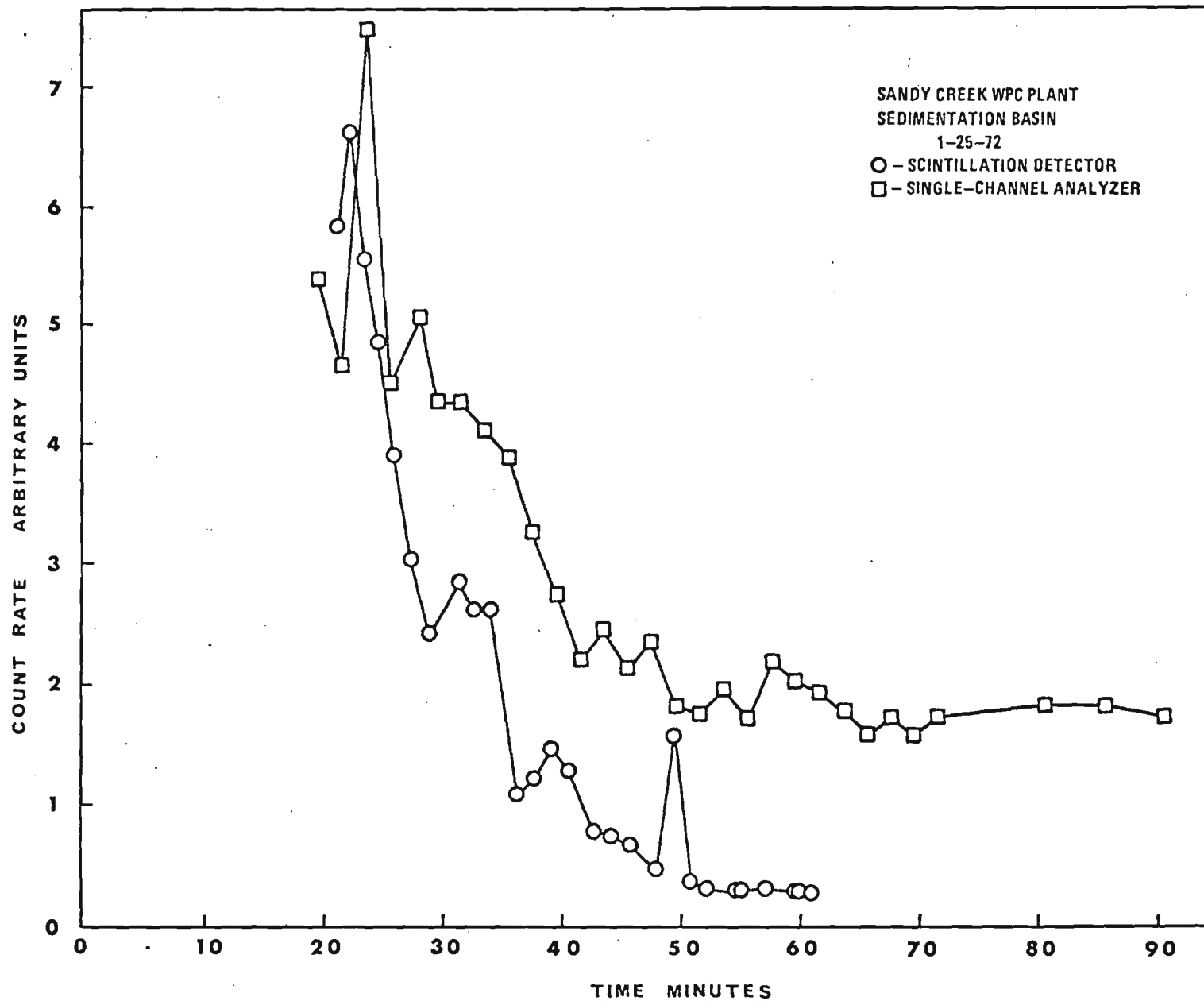


Figure 14. Field Measurements of Radioactivity at Sandy Creek WPC Plant



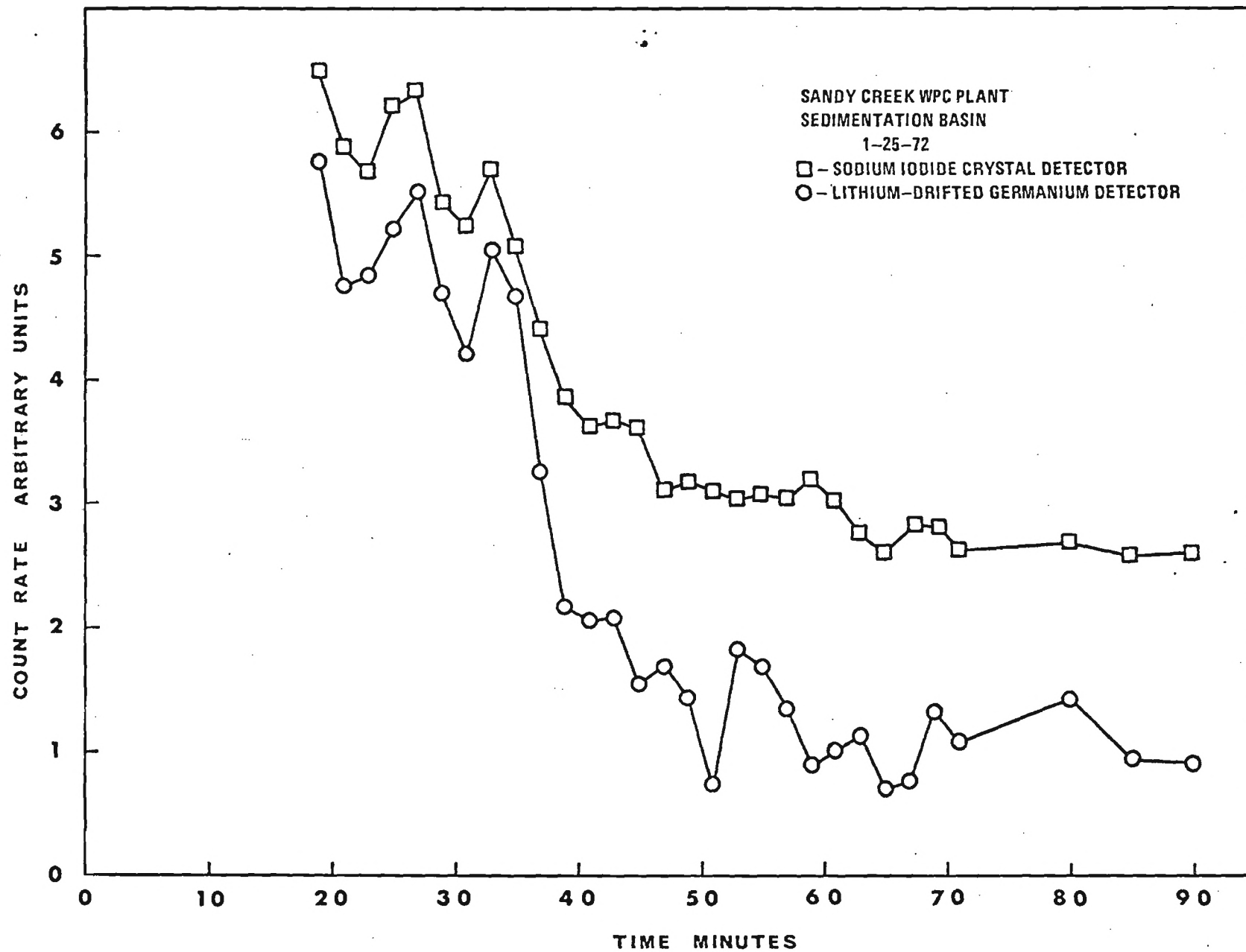


Figure 15. Laboratory Measurements of Radioactivity from Samples Taken at Sandy Creek WPC Plant

although moving very slowly, does indeed influence the flow pattern in the basin. There was also visual evidence from the behavior of the dye. During the early stages of the run, no dye color was visible except at the outlet weir, where the flow rises to enter the effluent trough. After the flights began to move, color became evident throughout the basin, even in the first quarter of the tank. It was apparent that the liquid containing the dye was being mixed with the overlying sewage of normal gray color.

From the results of this test, it is concluded that the movement of the sludge collecting mechanism exerts a major influence on the pattern of fluid movement within the basin. The desirability of interfering with the natural pattern would depend on the manner in which a basin is operating. A temperature differential which moves flow directly to the lower section of a tank admittedly carries suspended matter quickly to the bottom, but as the flow involves only a fraction of the cross-sectional area of the tank, the velocity is many times greater than intended. Solid matter is therefore swept along in the current, and efficiency of sedimentation is poor. Under these conditions, an interruption in this flow pattern would be advantageous. However, if there were no short-circuiting in a basin, the movement of liquid induced by the motion of the sludge scraping flights might hinder the settling of suspended matter.

The test illustrated the value and disadvantages of using a radioactive tracer in such work. The ability to analyze samples immediately at the plant is an undoubted advantage. On the other hand, it requires moving fairly complex and delicate equipment to a rather uncongenial location, the transportation and handling of a rather large amount of radioactive material, and a substantial amount of preliminary work to overcome licensing and psychological barriers.

#### Digester Volume Studies

There is no problem in measuring the dimensions of an anaerobic digester and calculating its volume. However, sand and other matter typically accumulates on the bottom of digesters, reducing their usable volume. It is difficult to ascertain the volume in active use at any time because of the uncertainty of locating the surface of the deposited material and its likely non-uniformity. It is inconvenient to probe into a mass of viscous matter contained in a tank under an atmosphere containing pressurized methane.

It was believed that measurement of active volume could be made by adding a known quantity of activable isotope, mixing the digester contents thoroughly, and then determining the concentration of the isotope. While this procedure is simple enough in theory, its application was found to be impractical.

The first digester volume experiment was carried out at the Sandy Creek Plant. Fifty grams of indium were dissolved in nitric acid and diluted to five gallons with tap water. This was slowly poured into the sludge sump while sludge was being pumped into the digester. The digester contents are customarily mixed by pumping from one location in the tank to another for several hours each day. At intervals of a few days during the next several weeks quart samples were removed from the digester and analyzed. The results were extremely erratic and were considered meaningless. The data are shown in Figure 16. This situation was apparently caused by non-uniformity of the digester contents complicated by the periodic removal of the supernatant liquid. While the mixing obtained in this digester is obviously sufficient for the desired biological processes, it is concluded that, in the physical sense, the digester contents are very poorly mixed.

Attention was subsequently shifted to the Marsh Creek Plant where the digester is equipped with a Perth unit and is considered to be the best mixed digester in the Atlanta system. The Perth system collects gas from the top of the digester and blows it sequentially through six pipes which extend almost to the bottom of the tank. The rising gas bubbles agitate and mix the digester contents. Also the tank is equipped with a pump which transfers material from the bottom to the top of the tank and provides an even greater degree of uniformity.

Fifty grams of indium in five gallons of water were introduced into the digester through the sludge sump in the same manner as at the Sandy Creek Plant. Samples were removed from the digester daily for several days and at long intervals over a total period of 84 days. A tally was kept of the sludge added and the supernatant removed, but even if these changes were taken into consideration no definite volume could be inferred. More than one sample was usually collected on each sampling day, but the

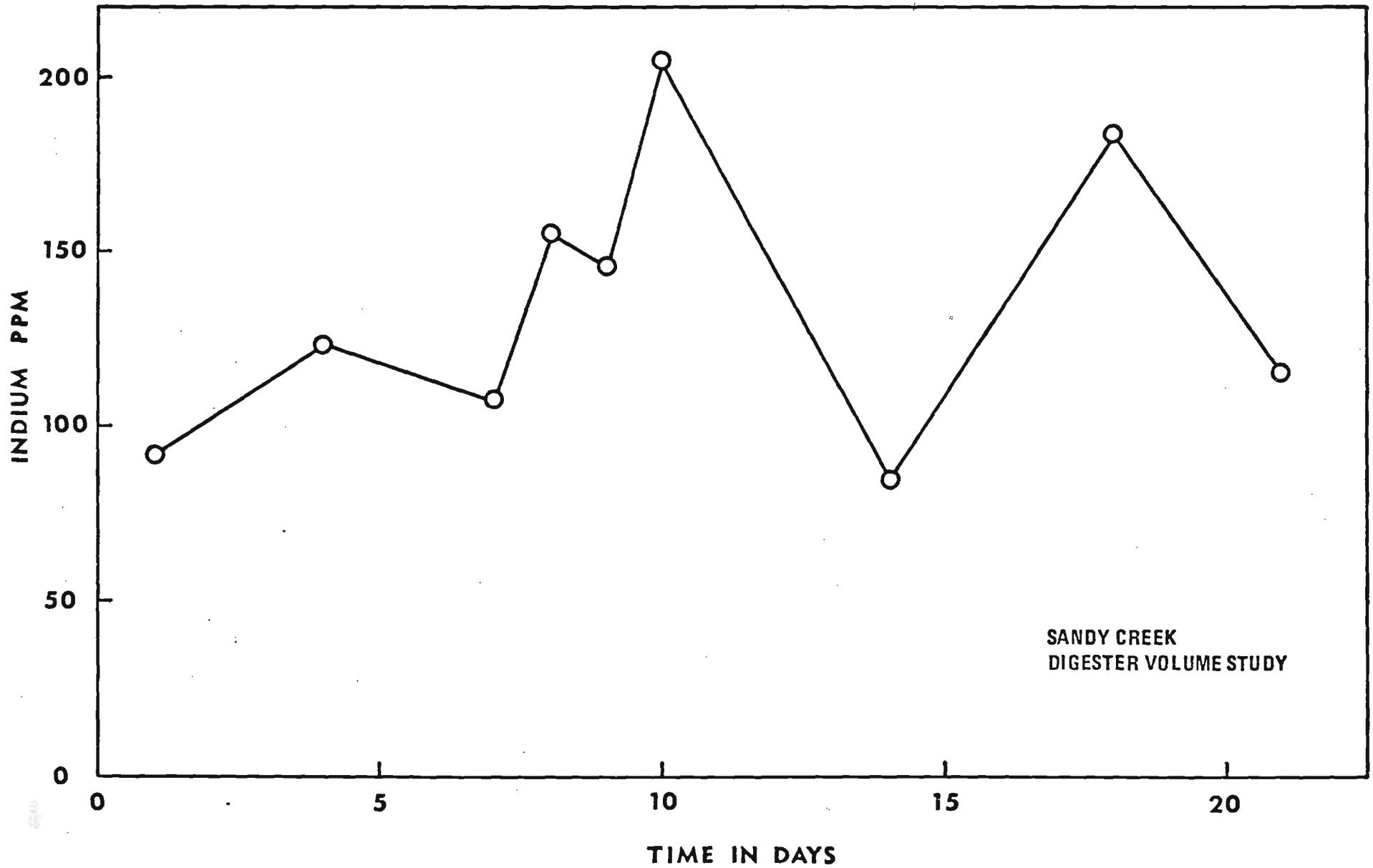


Figure 16. First Digester Test - Sandy Creek Plant

analysis of no two samples ever agreed very closely. The largest difference occurred on day 15, when one sample was found to contain less than 100 ppm indium while the other gave a value near 300. The results are shown in Figure 17.

Based on these experiments at two different plants, it is concluded that the procedures utilized are unlikely to give satisfactory results. Some of the difficulty might be overcome by initially dispersing the tracer in a larger volume of water. This should facilitate mixing, but excessively large volumes would probably be required.

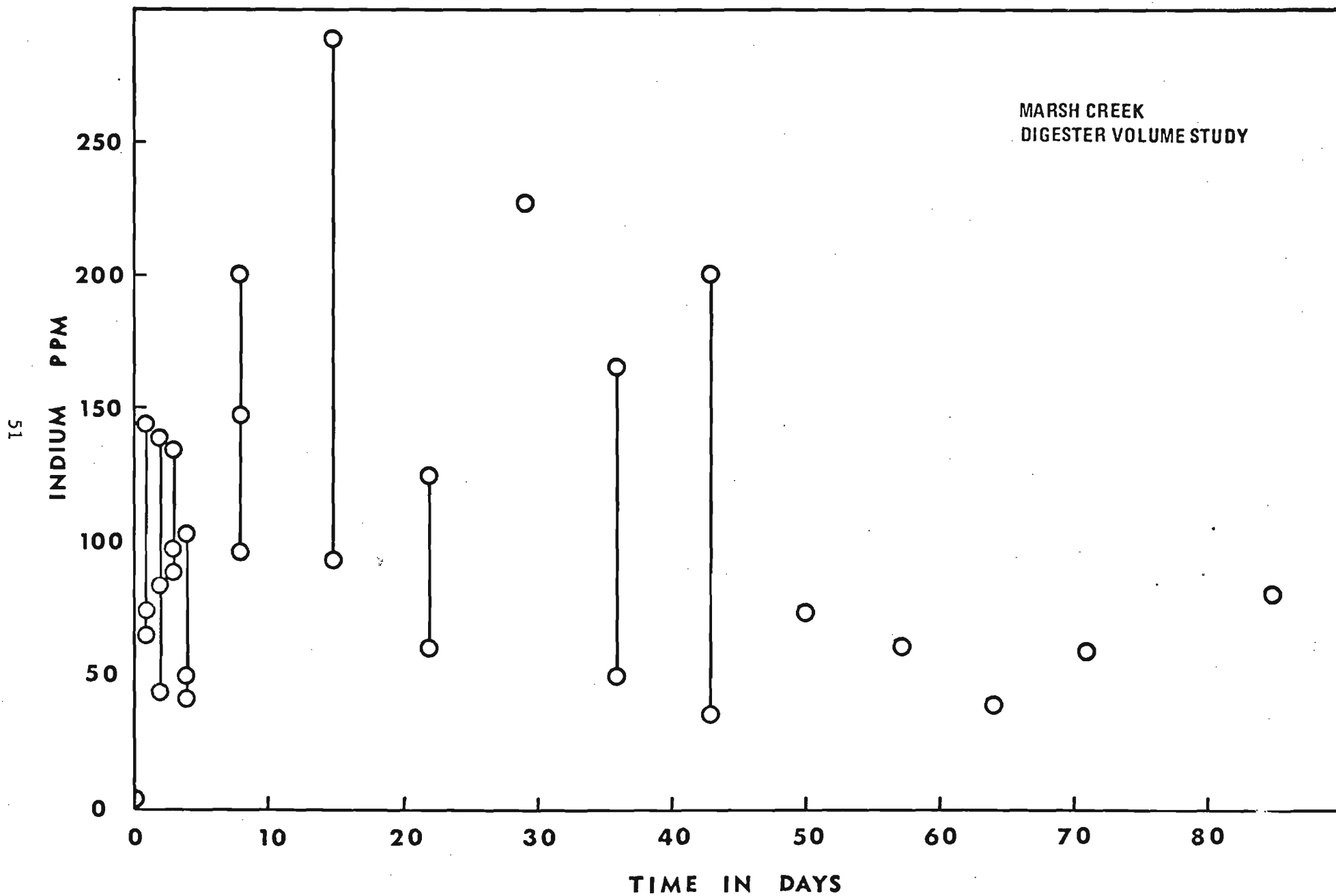


Figure 17. Second Digester Test - Marsh Creek Plant



## DISCUSSION

The test work described here has shown clearly that the use of stable tracers with post-sampling activation analysis is practical in sewage treatment plants and can yield valuable data of practical significance. While the time delay in analyzing the samples is a drawback compared with the instantaneous indication available with radioactive tracers, the lack of red tape and of the psychological problems associated with the use of anything radioactive in the public domain tend to balance this.

In two instances, plant superintendents were aware of basin short-circuiting, but had no idea as to the severity of the problem. Although this is not a matter that can be changed by any simple means, the tests helped explain some of the poor operating results that have occurred from time to time. The discovery of a very regular periodic recirculation pattern in the Sandy Creek basin was not anticipated, and was viewed with great interest. It was obvious to all concerned that a moving object will influence the flow pattern in a basin, but the magnitude of the effect was enlightening. Further work is needed to verify that the sludge collector is the cause of this phenomenon, and to determine if a different schedule of operation would give better efficiency. Further test work is needed to demonstrate applications to other types and portions of treatment plants, especially for sludge handling.

The cost of the work also needs evaluating on a realistic basis. Indium is a relatively expensive tracer material, and there is an incentive to use a cheaper material for those systems where this appears to be practical. Similarly, the activation services and gamma-ray analysis can be performed at lesser cost once the development phase is past. If the sampling can be done by the normal plant operating personnel, a major cost factor can be eliminated. These and related aspects deserve to be studied further.

## INFORMATION TRANSFER

One of the practical problems associated with the development of rather sophisticated test and analysis procedures is to obtain their subsequent acceptance and use by the industry involved. This is particularly difficult in an area such as wastewater treatment work where there are few normal contacts between the industry and the universities or national laboratories. For this reason it was considered of crucial importance to the project to involve plant personnel in the region, to stimulate personal contacts and to conduct demonstrations as far afield as possible. Unfortunately, termination of the project has cut off several such demonstrations planned in 1973-1974.

Papers on the techniques involved and the criteria used in the selection of appropriate tracer materials were presented at the meeting of the Georgia Water Pollution Control Association in Augusta, Georgia in 1971 and the winter meeting of the American Nuclear Society, Miami, Florida, also in 1971.

### Short School Participation

Twice each year the Georgia Water and Pollution Control Association and the Environmental Protection Division of the Georgia Department of Natural Resources sponsor a training school for water and wastewater plant operators. These schools typically last for 3 or 4 days and offer intensive instruction in basic and advanced water and wastewater treatment. Attendance at the basic course provides new operators with fundamental information that aids in the performance of their duties and helps to prepare them for examinations for Class III and IV Certification. The advanced courses provide more detailed information intended to expand the knowledge of the attendees and to prepare them for Class I and II examination.

The 1972 Fall Operator Training School was held November 14-17, 1972 on the campus of South Georgia College, Douglas, Georgia. Total enrollment was approximately 150, with about 30 registered for the advanced wastewater course. More than 20 different treatment plants were represented. The program included a one hour lecture and demonstration of the

use of tracers. The general use of tracers for studying the operation of treatment plants was described and details of the post-sampling neutron activation technique were presented.

A bus was provided to transport the class to the Douglas sewage treatment plant where a demonstration of the tracer technique was held. A mixed indium and dye tracer was used, and selected members of the group collected samples at strategic points in the plant. Others participated by recording the time of collection of each sample. The samples were subsequently transported to the laboratory for neutron activation analysis. The results of the analysis and their accompanying explanation are as follows:

"In the operation of wastewater treatment plants problems arise from time to time that cannot be solved by routine procedures. It then becomes necessary to resort to less-frequently used techniques of investigation in order to locate the cause of the difficulty. One method is to use a tracer, which can supply information on flow patterns and other dynamic variables that cannot be obtained by other means. The U.S. Atomic Energy Commission has been sponsoring work at the Engineering Experiment Station at Georgia Tech on the use of tracers for the study of treatment plants, and the November 15, 1972 session was intended to demonstrate the technique that has been developed.

"It was shown that there is nothing particularly difficult about adding inert tracer material and obtaining samples, although care is necessary in timing and collecting the samples. The analysis of the samples was carried out at the Engineering Experiment Station, using the Georgia Tech Research Reactor for neutron activation. The results were plotted as shown in the accompanying Figure 18 in this report.

"The Douglas treatment plant was operating in normal fashion at the time of the demonstration, and the plots are typical. There is a high peak in curve A (trickling filter outlet) because the tracer was moving in a rather compact slug. By the time it reached the secondary clarifier (Curve B) the peak was lower, due to mixing. Curves C and D represent concentrations at the outlet end of each side of the secondary clarifier.

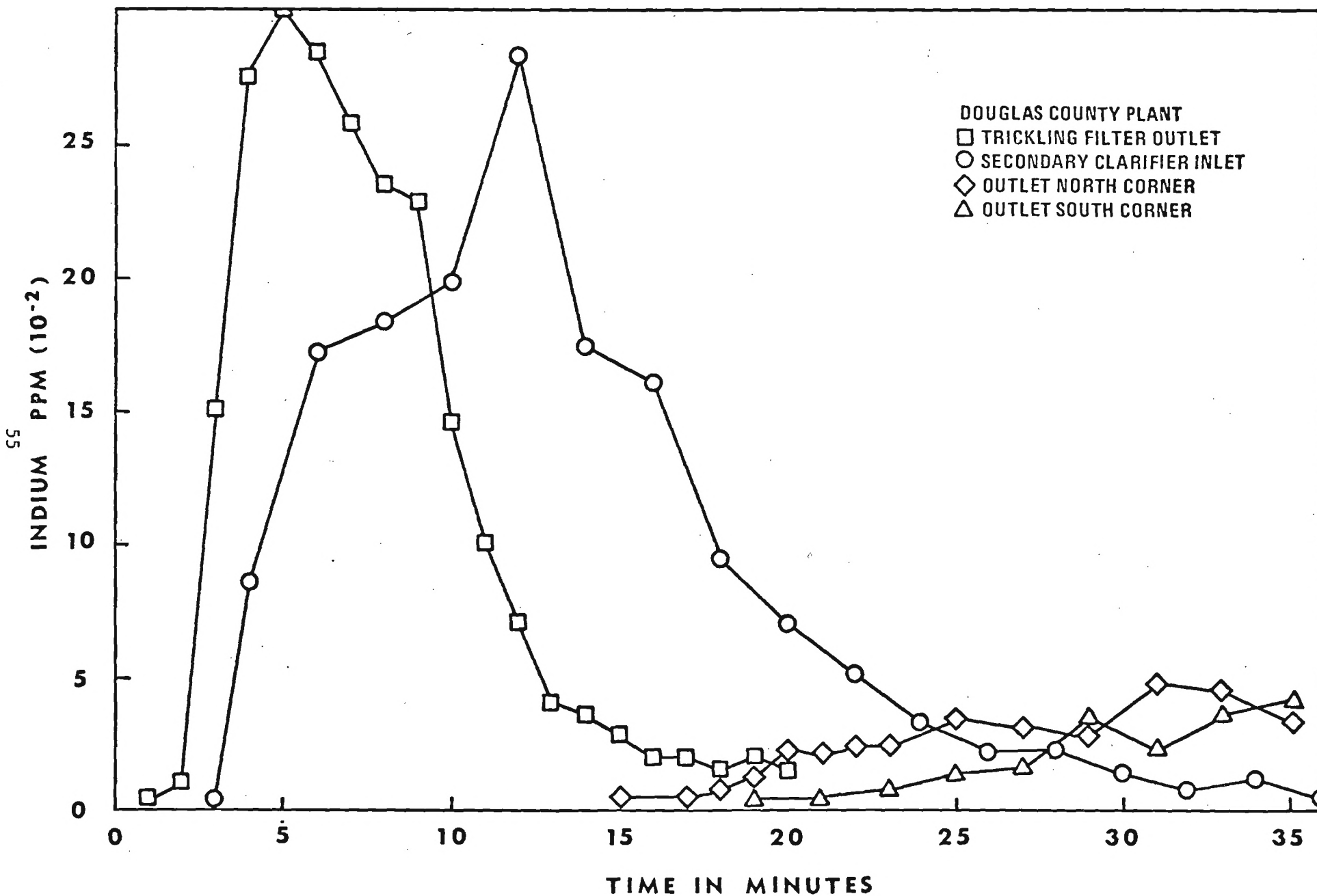


Figure 18. Tracer Plot - Douglas Demonstration

These curves are quite similar, and it appears that the flows through each side of the basin are about equal. If there had been trouble in the clarifier, more tracer would have appeared in one outlet than in the other.

"It is hoped that the lecture and demonstration which you have attended will encourage you to use the same technique in your own plant if the need should ever arise. For working out details of obtaining tracer and performing the analyses, contact Nuclear and Biological Sciences Division, Engineering Experiment Station, Georgia Tech, Atlanta, Georgia, 30332."

#### Technology Transfer Session

A brief training session on tracer techniques was held at the Macon, Georgia sewage treatment plant and was attended by representatives of five municipalities. The program began with a lecture to introduce and explain the concepts and procedures involved. This was followed by a question and answer period in which many of the attendees actively participated. A demonstration was then carried out with various members of the group assisting by timing and collecting samples.

The collected samples were subsequently analyzed and graphs of the data prepared. A description of the demonstration was written and a copy was mailed to all those who were present. The content of the mailed material is presented in Appendix B, and represents an example of a training approach that was considered appropriate and successful in this context.

Further demonstrations at other meetings in various southeastern states had been planned.

## CONCLUSIONS

The work described in this report has shown that post-activation analysis of stable tracers offers a simple approach for the evaluation of sewage treatment plants, with considerable advantages over dye tracers and radiotracer tests used commonly in water studies. It is felt that there would be few obstacles to acceptance by the industry and, with some training, the cost of testing and sampling can be reduced to a level easily compatible with the benefits derived from proper operation of all water pollution control facilities. Considerably more work needs to be done to demonstrate the application of the technique in representative treatment plants and to develop a fair economic assessment of the cost and benefits of this procedure.



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#### ACKNOWLEDGEMENTS

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#### PAPERS PRESENTED

Craft, T. F., "Tracer Methods for the Evaluation of Waste Treatment Processes," Georgia Water and Pollution Control Association Annual Conference, Augusta, Georgia, September, 1971

Eichholz, G.G., "Use of Post-Sampling Activation Analysis in Sewage Treatment Plants," American Nuclear Society 1971 Winter Meeting, Miami Beach, Florida, October, 1971 Trans. ANS, 14, 469 (1971).

# LIST OF PERSONNEL

Geoffrey G. Eichholz	Project Director	Jan. 1971-Mar. 1973
T. F. Craft	Principal Investigator	Jan. 1971-Mar. 1973
Steven N. Millspaugh	Research Technician	Jan. 1971-Mar. 1973
Timothy M. Galbreth	Grad. Research Asst.	Jan. 1971-Dec. 1971
Thomas D. Enyeart	Grad. Research Asst.	Jan. 1972-Aug. 1972
Thomas A. Coleman	Grad. Research Asst.	Sept. 1972-Mar. 1973
D. Dziadosz	Grad. Research Asst.	Sept. 1972-Mar. 1973

## APPENDIX A

### SPECTRAN: A FORTRAN PROGRAM TO ANALYZE GAMMA-RAY SPECTRA

by David Dziadosz

Manual analysis of gamma-ray spectra is a cumbersome task regardless of the number of spectra to be analyzed. Such is the case in the analysis of river and treatment plant water samples. Many samples must be examined by using neutron activation analysis with the end result being an accumulation of large amounts of data to be analyzed. Analysis of gamma-ray spectra is handled much more efficiently and quickly with the use of a computer. Both large and medium size computers have been used with success as the literature<sup>(1-4)</sup> shows.

Since radionuclides are easily characterized by their half-lives and gamma radiation energies, analysis of unknown samples for trace elements can be done using neutron activation analysis and gamma-ray spectrometry. From this analysis, the isotopic constituents of an unknown sample can be determined either qualitatively or quantitatively. Before the constituents of an unknown sample can be determined, the spectrum of the unknown sample has to be scanned to find all valid photopeaks and their corresponding locations. Using the photopeak locations and energy calibration parameters, the energies of the gamma-rays can then be determined. The problem is though, that most spectra are very complex and may contain some twenty to forty photopeaks each. Manual analysis of such spectra is time consuming and can be handled much more efficiently on a computer.

SPECTRAN was written to analyze these complex spectra and provide the useful information needed quickly. It is used to locate all photopeaks contained in the spectrum and test them for their statistical validity. From this the corresponding energies can be determined. It also matches these energies to corresponding tabulated gamma-ray energies<sup>(7)</sup> of known isotopes. A flow chart (Fig.19) of SPECTRAN is given with a more detailed discussion following.

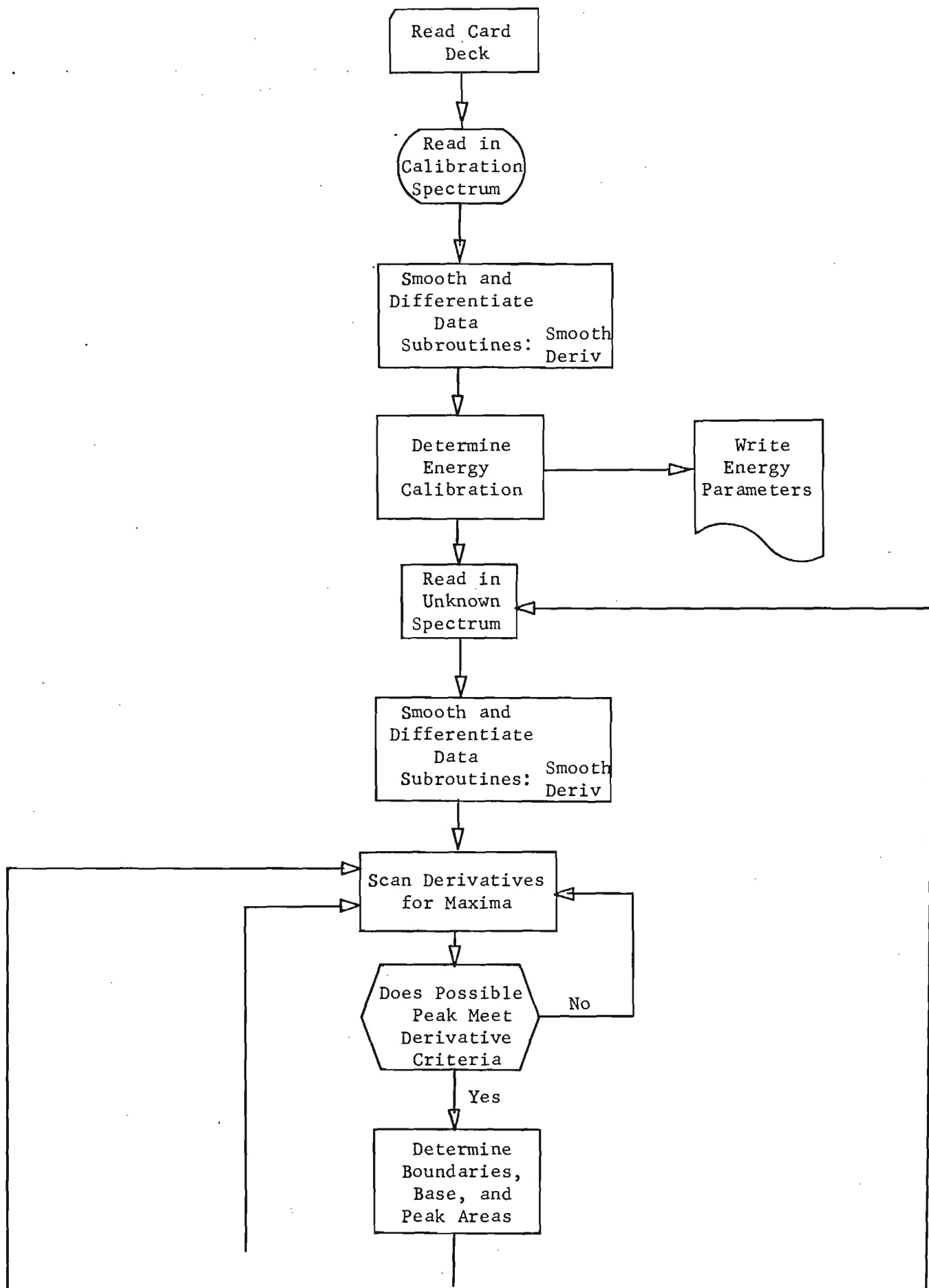


Fig.19a Flow Chart of SPECTRAN



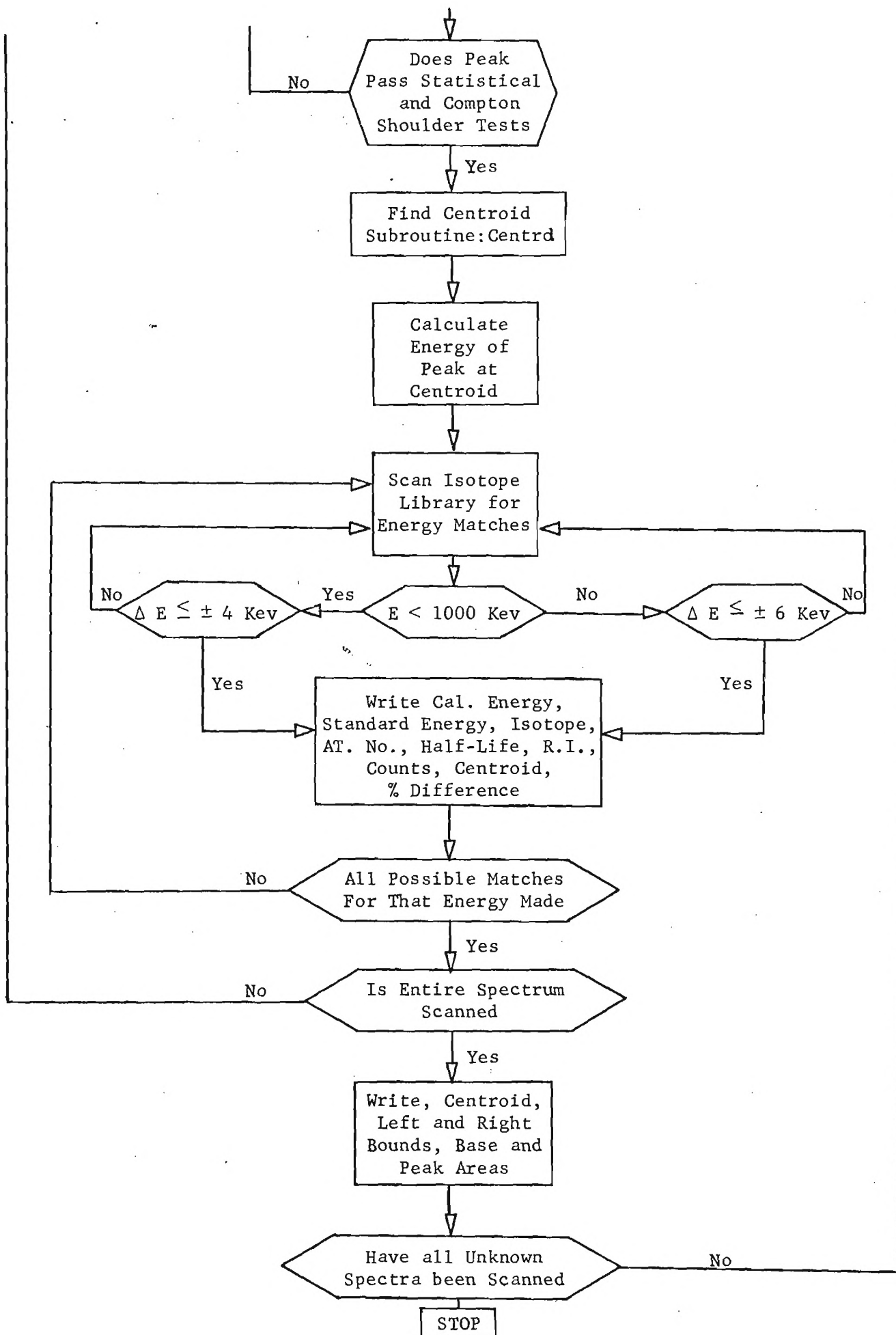


Fig. 19a Flow Chart of SPECTRAN

## DATA RETRIEVAL AND SETUP

All samples were irradiated in the Georgia Tech Research Reactor which is a heavy-water moderated, 1 megawatt reactor with a neutron flux of about  $10^{13}$  n/cm<sup>2</sup>sec. The irradiated samples were then analyzed using a Ge(Li) detector and a 1024 multi-channel analyzer.

The data was removed from the analyzer by using a remote teletype terminal equipped with a paper tape puncher. The teletype was linked to the analyzer memory. The paper tapes were then read into a file using a remote teletype terminal equipped with a paper tape reader. This terminal was hooked on-line with the UNIVAC 1108. In this way the data could be edited for punching errors and at the same time be put into a FASTRAN file in the UNIVAC 1108. With the data in file, it could be called by the program with the simple insertion of proper control cards.

In setting up each section of the data card deck, the number of data cards in each section to be read was specified in the main program. This was done by the use of a FORTRAN PARAMETER statement. In this statement the following constants are defined:

MAN: number of spectra to be scanned including calibration spectrum

MZ : number of calibration peaks used in calibration

MO : number of standard tabulated gamma energies in isotope library

In changing the data decks from run to run, only the PARAMETER statement in the main program needs to be changed.

It is important that the data deck be set up in the following way.

### 1) ISOTOPE LIBRARY

MO punched cards where the following information for each isotope is punched on each card;

- a) an isotope name (ELEMNT)\*
- b) the atomic number of that isotope (ATNO)
- c) an associated gamma-ray energy in kev (ENERGY)
- d) the relative intensity of the particular gamma-ray (RI)
- e) the isotope's half-life (HALFLF)
- f) the half-life units of time (e.g., H for hours, S for seconds, etc.) (TIME)

An example of the card format is given in Fig. 20a.

---

\* ( ) denotes array name used in Fortran Program

## 2) CALIBRATION PARAMETERS

MZ punched cards where the following information for each calibration source used is punched on each card.

- a) an isotope name (ECEL)
- b) the atomic number of that isotope (ECAT)
- c) an associated gamma-ray energy is keV (EC)

An example of the card format is given in Fig. 20b.

## 3) SPECTRAL DATA

MAN punched cards which calls the spectral data from the FASTRAN file.

The first set of data called must be the calibration spectrum.

After that card the other MAN-1 cards call the unknown spectra to be analyzed. All of the data is then kept in storage in the main program during execution. An example of a calling control card is shown in Fig. 20c.

## PROGRAM OUTLINE AND DISCUSSION

After the data is read in at the beginning of the main program; the next step is to calibrate the analyzer using the calibration spectrum obtained. The calibration spectrum is smoothed and corresponding derivatives calculated using well known convolution techniques<sup>(5)</sup>. Five points were used in smoothing and differentiation by subroutines SMOOTH and DERIV respectively. Since it is assumed that there is a linear relationship between energy and channel, an approximate value of the energy per channel must be guessed. An example of this is if it is known that there is about 2 keV/channel for a certain analyzer a guess of about 2.20 keV/channel should be made. The reason for a larger guess than actual energy per channel will be evident shortly. The first calibration energy is divided by the guess value (energy/channel) and in this way a location to the left of the peak is found. The position to the left of the peak is needed so as to not pass the peak location on the right before it starts to scan for it. This is the reason for the larger guess. Also in this way only the parts of the calibration spectrum containing the calibration peaks is scanned. From this approximate location a search is started for the actual peak location. Criteria for establishing a peak will be discussed later on. After the

Columns	1-6	7-10	11-20	21-25	26-35	36
Array Name	ELEMNT	ATNO	ENERGY	RI	HALFLF	TIME
Format	A6	I4	F10.1	F5.1	F10.2	A1

Fig. 20a. Format Specifications for Isotope Library

Columns	1-6	7-10	11-20
Array Name	ECEL	ECAT	EC
Format	A6	I4	F10.1

Fig. 20b. Format Specifications for Calibration Parameters

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
7/8	A	D	D		S	P	E	C	D	A	T	A	.	R	U	N	1		

SPECDATA → File Name

Run 1 → Particular Spectrum to be Analyzed

Fig. 20c. Example of Calling Control Card

peak has been located the left and right bounds of the peak are found. With these parameters now known the centroid of the peak is calculated by the subroutine CENTRD. This procedure is followed until all calibration peaks have been located. Since it was assumed that there was a linear relationship between energy and channel, a least squares fit is made and the "true" values for the energy per channel and energy offset are found. Now that the analyzer has been calibrated, the unknown spectra can be scanned.

Before the unknown spectra are scanned they are smoothed and derivatives calculated as before by SMOOTH and DERIV. The derivatives are scanned for the following conditions:

- 1)  $DCDE(M-1)$  and  $DCDE(M)$  both greater than zero, and  $DCDE(M+1)$  less than zero where  $DCDE$  is the derivative found using the smoothed data.

If this condition is fulfilled then following condition must be met:

- 2)  $DCDE(M+1)$ ,  $DCDE(M+2)$ ,  $DCDE(M+3)$ , all must be less than zero.

If this condition is not met, the program returns to scanning the derivatives until the first condition is fulfilled again.

If the second condition is met the program searches the possible peak for the channel which has the maximum counts in it using the smoothed data. This channel will be used as the peak

channel to be used later in calculating the centroid of that peak.

The left and right boundaries of the peak are found next. The boundaries are found under the assumption that they are at the points where the minimum number of counts occur on the left and right sides of the peak. This method of finding the boundaries generally gives very good results.

Now that the left and right boundaries have been found, the base and peak areas can be calculated. There are many sophisticated methods<sup>(6)</sup> given for photopeak integration to be used on a computer. For simplicity the following formulas were used which are given by Yule<sup>(4)</sup>.

$$\text{Base Area} = \frac{1}{2} (D_L + D_R) \times (R - L - 1) \quad (1)$$

$D_L \equiv$  counts at left boundary

$D_R \equiv$  counts at right boundary

$R \equiv$  right boundary channel

$L \equiv$  left boundary channel

From this the peak area can be calculated.

$$\text{Peak Area} = \sum_{i=L+1}^{R-1} D_i - \text{Base Area} \quad (2)$$

$D_i =$  counts in  $i$ th channel

After calculating the base and peak areas the peak is tested for statistical validity. The criterion established by Yule<sup>(4)</sup> was used.

$$\text{PEAK AREA} > 3 \times (\text{BASE AREA})^{\frac{1}{2}}$$

If this test is passed the centroid of the peak is found, if not, the program returns to scanning the derivatives.

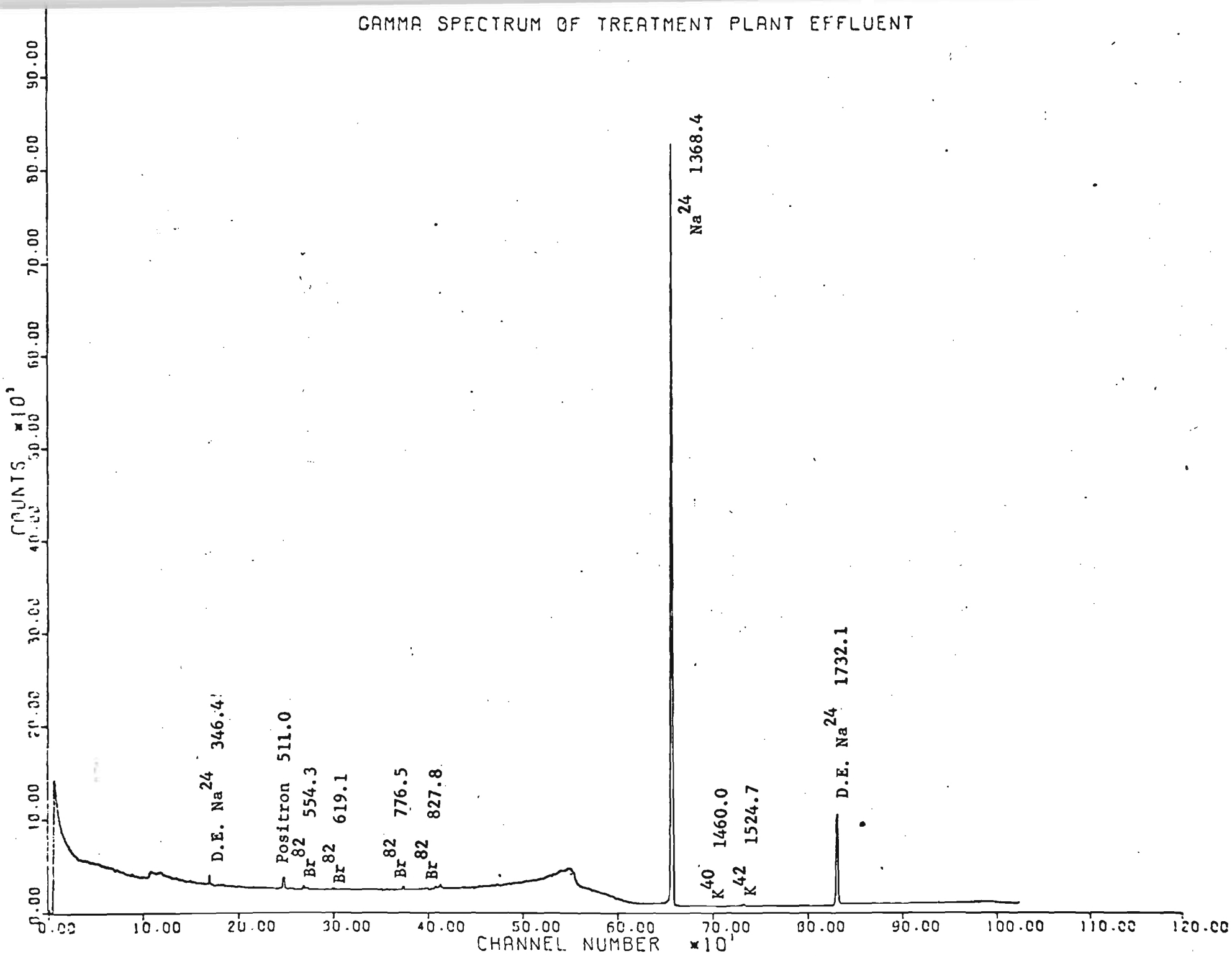
Up to this point nothing has been said about the elimination of Compton shoulders. Due to the high resolution of the Ge(Li) detector, it has been observed the peak widths at the base are never greater than about 12 channels. Therefore, it was concluded that any possible peak found over 18 channels in width at the base was a Compton shoulder. This criterion has never eliminated any valid photopeaks nor has it led to the acceptance of a Compton shoulder as a valid photopeak.

Now that the peak energy was determined, the isotope library was scanned to find the closest matching energies of standard isotopes to that which was calculated. The library was scanned each time a valid peak and its corresponding energy was found. For energies less than a 1000 keV, a standard isotope having an energy within  $\pm 5$  keV of the calculated energy was considered a match. For energies greater than a 1000 keV;  $\pm 6$  keV was the limit used in matching. This can lead to more than one possible match for each calculated energy. Since information such as relative intensity and half-life are given for each isotope, and knowing the irradiation time, elimination of meaningless matches can be made in interpreting the results.



After a complete spectrum has been scanned, a new spectrum can be read in and processed. Because of the relatively large memory of the UNIVAC 1108, many spectra may be processed in one run. A complete listing of the program and output will be given in APPENDIX A'. Figure 21 will show a sample spectrum and the peaks located by the program.

# GAMMA SPECTRUM OF TREATMENT PLANT EFFLUENT



## RESULTS AND CONCLUSIONS

The spectrum shown in Fig. 21 was obtained by irradiating a 1 cc sample of treatment plant effluent for 1 hour. In this case, the determination of all long-lived isotopes ( $T_{1/2} > 6$  hr.) was sought. A complete listing of the photopeaks found by the program and their respective energies is given in Appendix A'. Some of the more discernible peaks are labeled in Fig. 21. It should be noted that some of the peaks found by the program do not appear in the plot due to scaling techniques used by the CALCOMP plotter, but by manually inspecting the raw data these peaks can be shown to exist.

As mentioned earlier, there may be more than one isotope match with a certain photopeak. For example, this is the case for the photopeak found at 620.7 keV. The output shows that  $\text{Br}^{82}$  and a double escape peak of  $\text{Cl}^{38}$  have energies very close to 620.7 keV. By looking at the information given, one can conclude that the photopeak results from  $\text{Br}^{82}$  radiation. In this way meaningless matches can be eliminated.

The output also shows that certain photopeak energies have no matches at all. Generally the reason for this is that the peaks with no matches are due to incidental peaking in the background, but it should be emphasized that the isotope library given is by no means complete and unidentified peak energies may not be contained in the library.

Peak energy calculations were generally very good. It was found that using the centroid of the peak gave better results than using the channel where the maximum counts occurred. With more accurate energy calculations, the identification of isotopes was made much easier.

The information obtained from the program can also be used for quantitative studies. At this point though, the program is not equipped to do any isotopic concentration studies. This must be done manually. Future work will include the addition of a subroutine to calculate isotopic concentrations in unknown samples and making the isotope library more complete.

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## APPENDIX A'

### PROGRAM LISTING AND OUTPUT

C

PARAMETER MO=91,MAN=3,MZ=2,NCHL=1024

C

C MO=NUMBER OF ISOTOPES IN THE ISOTOPE LIBRARY

C MAN=NUMBER OF SPECTRA TO BE SCANNED

C MZ=NUMBER OF CALIBRATION PEAKS USED IN CALIBRATING

C NCHL=NUMBER OF CHANNELS IN ANALYSER

C

INTEGER ATNO,ECAT

DIMENSION ELEMNT(MO),ATNO(MO),ENERGY(MO),EC(MZ),ECAT(MZ),ECEL(MZ),

ICH(MZ),IC(MAN,NCHL),CTRD(MZ),RI(MO),HALFLF(MO),TIME(MO),X1(50),

IL2(50),L3(50),X4(50),X5(50),MDATA(NCHL),DCDE(NCHL)

READ(5,101) (ELEMNT(I),ATNO(I),ENERGY(I),RI(I),HALFLF(I),TIME(I),

II=1,MO)

101 FORMAT(A6,I4,F10.1,F5.1,F10.2,A1)

READ(5,102) (ECEL(I),ECAT(I),EC(I),I=1,MZ)

102 FORMAT(A6,I4,F10.1)

DO 977 I=1,MAN

READ(5,100) (IC(I,L),L=1,NCHL)

977 CONTINUE

100 FORMAT(I6,9I7)

WRITE(6,99)

99 FORMAT(1H1,5X,7HELEMENT,5X,13HATOMIC NUMBER,5X,11HENERGY(KEV),5X,

113HREL,INTENSITY,5X,9HHALF LIFE)

WRITE(6,98) (ELEMNT(I),ATNO(I),ENERGY(I),RI(I),HALFLF(I),TIME(I),

II=1,MO)

98 FORMAT(1X,5X,A6,9X,I4,10X,F10.1,11X,F5.1,9X,F10.2,A1)

WRITE(6,1600)

1600 FORMAT(1H0,90HP=511.0 KEV:WHERE P IS INDICATED,THE ENERGIES REPRES

ENT ESCAPE PEAKS OF THAT ISOTOPE)

C

C WHEN JO=1: JO DESIGNATES THE CALIBRATION SPECTRUM; JO>1: JO DESIGNATES

C THE SAMPLE SPECTRA

C

JOB=0

JO=1

C

C SUBROUTINE SMOOTH: SMOOTHES RAW DATA USING 5PT CONVOLUTION DATA

C SUBROUTINE DERIV: CALCULATES 1ST DERIVATIVE USING 5PT CONVOLUTION DATA

C

CALL SMOOTH(JO,MAN,IC,NCHL,MDATA)

CALL DERIV(NCHL,MDATA,DCDE)

C

C FIND PEAK LOCATIONS IN CALIBRATION SPECTRUM

C

JIM=1

GUESS=2.11

507 MIA=EC(JIM)/GUESS

501 IF(DCDE(MIA-1).GT.0.0.AND.DCDE(MIA).GT.0.0.AND.DCDE(MIA+1).LT.0.0)

160 TO 500

MIA=MIA+1

GO TO 501

500 IF(DCDE(MIA+1).LT.0.0.AND.DCDE(MIA+2).LT.0.0.AND.DCDE(MIA+3).LT.0.

10) GO TO 502



```

      MIA=MIA+1
      GO TO 501
502 IF(MDATA(MIA)-MDATA(MIA-1)) 503,503,504
504 IF(MDATA(MIA)-MDATA(MIA+1)) 506,506,510
503 ICH(JIM)=MIA-1
      GO TO 508
506 ICH(JIM)=MIA+1
      GO TO 508
510 ICH(JIM)=MIA
508 M=ICH(JIM)
      N=M-1
40 IF(MDATA(N)-MDATA(N-1)) 41,41,42
41 LB=N
      GO TO 43
42 N=N-1
      GO TO 40
43 NN=M+2
44 IF(MDATA(NN)-MDATA(NN+1)) 45,45,46
45 IRB=NN
      GO TO 8000
46 NN=NN+1
      GO TO 44
8000 B1=0.5*(MDATA(LB)+MDATA(IRB))*(IRB-LB-1)
      PI=0.0
      NO=LB+1
      NI=IRB-1
      DO 5000 IO=NO,NI
5000 PI=PI+MDATA(IO)
      P2=P1-B1
      WRITE(6,9000) LB,IRB,B1,P1,P2
9000 FORMAT(1H0,I8,I8,3(E15.8))
      IF(P2.LE.0.0) GO TO 5001
      P3=5.0*SQRT(B1)
      IF(P1.GT.P3) GO TO 47
5001 MIA=MIA+3
      GO TO 501
47 CTRD=CENTRO(LB,IRB,M,NCHL,MDATA)
      CTRD(JIM)=M+CTRD
      JIM=JIM+1
      IF(JIM.GT.MZ) GO TO 509
      GO TO 507
C-----
C   ASSUMING LINEAR RELATIONSHIP BETWEEN ENERGY & CHANNEL (E=M*CH+B):
C   A LEAST SQUARES ROUTINE TO FIND THE SLOPE (M) & ENERGY OFFSET (B) IS USED
C-----
509 XAV=XAVE(CTRD,MZ)
      EAV=EAVE(EC,MZ)
      CSCP=SUMXYS(CTRD,EC,MZ)
      CSS=SUMXXS(CTRD,MZ)
      DE=CSCP/CSS
      A=EAV-DE*XAV
      WRITE(6,2000)
2000 FORMAT(1H1,40X,29HENERGY CALIBRATION PARAMETERS/1X,20X,7HELEMENT,
15X,13HATOMIC NUMBER,5X,11HENERGY(KEV),5X,12HPEAK CHANNEL,5X,
18HCENTROID)
      WRITE(6,520) (EC(I),ECAT(I),EC(I),ICH(I),CTRD(I),I=1,MZ)
520 FORMAT(1X,20X,A6,9X,I4,10X,F10.1,9X,I5,10X,F9.3)

```

```

WRITE(6,2001) XAV,EAV,CSCP,CSS,DE,A
2001 FORMAT(1H0,20X,3HXAV,15X,3HEAV,15X,4HCSCP,15X,
13HCSS/1X,14X,E15.8,3X,E15.8,3X,E15.8,4X,E15.8/1X,30X,45HENERGY-CHA
INNEL LINEAR RELATIONSHIP(E=DE*CH+BT)/1X,30X,6HSLOPE=,F12.8/1X,
119X,17HENERGY-INTERCEPT=,F14.8)
WRITE(6,528)
528 FORMAT(1H1,2X,7HCHANNEL,8X,3HRAW,8X,6HSMOOTH,8X,10HDERIVATIVE)
DO 530 I=1,NCHL
530 WRITE(6,531) I,IC(JO,I),MDATA(I),DCDE(I)
531 FORMAT(1X,3X,I4,8X,I8,6X,I8,7X,F12.4)
C-----
C SCAN EACH SPECTRUM
C-----
1002 JO=JO+1
IF(JO.GT.MAN) GO TO 1001
CALL SMOOTH(JO,MAN,IC,NCHL,MDATA)
CALL DERIV(NCHL,MDATA,DCDE)
WRITE(6,528)
DO 548 I=1,NCHL
548 WRITE(6,531) I,IC(JO,I),MDATA(I),DCDE(I)
WRITE(6,802)
802 FORMAT(1H1,100HCALC-ENERGY GAMMA-ENERGY ISOTOPE AT.NO. HALF-L
1IFE REL. INSTY RWCNTS CENTROID % DIFFERENCE)
C-----
C LOCATE ALL POSSIBLE PEAKS
C IF THERE ARE 2 POSITIVES, FOLLOWED BY A ZERO OR NEGATIVE SLOPE
C ***** POSSIBILITY OF A PEAK*****
C-----
M=40
7 IF(DCDE(M-1).GT.0.0.AND.DCDE(M).GT.0.0.AND.DCDE(M+1).LT.0.0)
160 TO 6
M=M+1
IF(M.GT.NCHL-3) GO TO 1000
GO TO 7
C-----
C IF THERE ARE LESS THAN 3 NEGATIVE DERIVATIVES ON RIGHT SIDE OF POSSIBLE
C PEAK, POSSIBLE PEAK DISREGARDED
C-----
6 IF(DCDE(M+1).LT.0.0.AND.DCDE(M+2).LT.0.0.AND.DCDE(M+3).LT.0.0)
160 TO 8
M=M+1
IF(M.GT.NCHL-3) GO TO 1000
GO TO 7
8 IF(MDATA(M)-MDATA(M-1)) 50,50,51
51 IF(MDATA(M)-MDATA(M+1)) 52,52,53
50 M=M-1
GO TO 600
52 M=M+1
GO TO 600
53 M=M
C-----
C CALCULATE LEFT AND RIGHT BOUNDARIES OF THE PEAK
C-----
C CALCULATE LEFT BOUNDARY
C-----
600 N=M-1
602 IF(MDATA(N)-MDATA(N-1)) 603,603,608

```

```

WRITE(6,2001) XAV,EAV,CSCP,CSS,DE,A
FORMAT(1H0,20X,3HXAV,15X,3HEAV,15X,4HCSCP,15X,
13HCSS/1X,14X,E15.8,3X,E15.8,3X,E15.8,4X,E15.8/1X,30X,45HENERGY-CHA
NNEL LINEAR RELATIONSHIP(E=DE*CH+B)/1X,30X,6HSLOPE=,F12.8/1X,
119X,17HENERGY-INTERCEPT=,F14.8)
WRITE(6,528)
FORMAT(1H1,2X,7HCHANNEL,8X,3HRAW,8X,6HSMOOTH,8X,10HDERIVATIVE)
DO 530 I=1,NCHL
WRITE(6,531) I,IC(JO,I),MDATA(I),DCDE(I)
FORMAT(1X,3X,14,8X,18,6X,18,7X,F12.4)

```

-----

FOR EACH SPECTRUM

-----

```

JO=JO+1
IF(JO.GT.MAN) GO TO 1001
CALL SMOOTH(JO,MAN,IC,NCHL,MDATA)
CALL DERIV(NCHL,MDATA,DCDE)
WRITE(6,528)
DO 548 I=1,NCHL
WRITE(6,531) I,IC(JO,I),MDATA(I),DCDE(I)
WRITE(6,802)
FORMAT(1H1,100HCALC-ENERGY GAMMA-ENERGY ISOTOPE AT.NO. HALF-L
IFE REL.INSTY RWCNTS CENTROID % DIFFERENCE)

```

-----

LOCATE ALL POSSIBLE PEAKS

THERE ARE 2 POSITIVES,FOLLOWED BY A ZERO OR NEGATIVE SLOPE

\*\*\*\*\* POSSIBILITY OF A PEAK\*\*\*\*\*

-----

```

M=40
IF(DCDE(M-1).GT.0.0.AND.DCDE(M).GT.0.0.AND.DCDE(M+1).LT.0.0)
GO TO 6
M=M+1
IF(M.GT.NCHL-3) GO TO 1000
GO TO 7

```

-----

THERE ARE LESS THAN 3 NEGATIVE DERIVATIVES ON RIGHT SIDE OF POSSIBLE

(,POSSIBLE PEAK DISREGARDED

-----

```

IF(DCDE(M+1).LT.0.0.AND.DCDE(M+2).LT.0.0.AND.DCDE(M+3).LT.0.0)
GO TO 8
M=M+1
IF(M.GT.NCHL-3) GO TO 1000
GO TO 7
F(MDATA(M)-MDATA(M-1)) 50,50,51
F(MDATA(M)-MDATA(M+1)) 52,52,53
M=M-1
GO TO 600
M=M+1
GO TO 600
M

```

-----

LOCATE LEFT AND RIGHT BOUNDARIES OF THE PEAK

-----

LOCATE LEFT BOUNDARY

-----

```

M-1
(MDATA(N)-MDATA(N-1)) 603,603,608

```

```

E(6,2001) XAV,EAV,CSCP,CSS,DE,A
AT(1H0,20X,3HXAV,15X,3HEAV,15X,4HCSCP,15X,
S/1X,14X,E15.8,3X,E15.8,3X,E15.8,4X,E15.8/1X,30X,45HENERGY-CHA
LINEAR RELATIONSHIP(E=DE*CH+BT/1X,30X,6HSLOPE=F12.8/1X,
17HENERGY-INTERCEPT=F14.8)

```

```

E(6,528)
AT(1H1,2X,7HCHANNEL,8X,3HRAW,8X,6HSMOOTH,8X,10HDERIVATIVE)

```

```

30 I=1,NCHL
E(6,531) I,IC(JO,I),MDATA(I),DCDE(I)
AT(1X,3X,I4,8X,I8,6X,I8,7X,F12.4)

```

```

-----
ACH SPECTRUM
-----

```

```

0+1
0.GT.MAN) GO TO 1001
SMOOTH(JO,MAN,IC,NCHL,MDATA)
DERIV(NCHL,MDATA,DCDE)

```

```

E(6,528)
48 I=1,NCHL
E(6,531) I,IC(JO,I),MDATA(I),DCDE(I)
E(6,802)

```

```

AT(1H1,100HCALC-ENERGY GAMMA-ENERGY ISOTOPE AT.NO. HALF-L
REL.INSTY RWCNTS CENTROID % DIFFERENCE)

```

```

-----
CATE ALL POSSIBLE PEAKS
E ARE 2 POSITIVES,FOLLOWED BY A ZERO OR NEGATIVE SLOPE
**** POSSIBILITY OF A PEAK*****
-----

```

```

DE(M-1).GT.0.0.AND.DCDE(M).GT.0.0.AND.DCDE(M+1).LT.0.0)

```

```

6

```

```

GT.NCHL-3) GO TO 1000

```

```

7

```

```

-----
ARE LESS THAN 3 NEGATIVE DERIVATIVES ON RIGHT SIDE OF POSSIBLE
SIBLE PEAK DISREGARDED
-----

```

```

E(M+1).LT.0.0.AND.DCDE(M+2).LT.0.0.AND.DCDE(M+3).LT.0.0)

```

```

8

```

```

Y.NCHL-3) GO TO 1000

```

```

7

```

```

A(M)-MDATA(M-1)) 50,50,51
A(M)-MDATA(M+1)) 52,52,53

```

```

00

```

```

00

```

```

-----
LEFT AND RIGHT BOUNDARIES OF THE PEAK
-----

```

```

LEFT BOUNDARY
-----

```

```

(N)-MDATA(N-1)) 603,603,608

```

TIME(I),  
1.4X,16.3X,

E AREA PEA



XAV,EAV,CSCP,CSS,DE,A  
 1H0,20X,3HXAV,15X,3HEAV,15X,4HCSCP,15X,  
 E15.8,3X,E15.8,3X,E15.8,4X,E15.8/1X,30X,45HENERGY-CHA  
 ELATIONSHIP(E=DE\*CH+37/1X,30X,6HSLOPE=F12.8/1X,  
 -INTERCEPT=F14.8)

,7HCHANNEL,8X,3HRAW,8X,6HSMOOTH,8X,10HDERIVATIVE)  
 HL  
 I,IC(J0,I),MDATA(I),DCDE(I)  
 I4,8X,I8,6X,I8,7X,F12.4)

RUM

GO TO 1001  
 O,MAN,IC,NCHL,MDATA)  
 HL,MDATA,DCDE)

HL  
 I,IC(J0,I),MDATA(I),DCDE(I)

ORCALC-ENERGY GAMMA-ENERGY ISOTOPE AT.NO. HALF-L  
 TY RWCNTS CENTROID % DIFFERENCE)

POSSIBLE PEAKS  
 POSITIVES,FOLLOWED BY A ZERO OR NEGATIVE SLOPE  
 BILITY OF A PEAK\*\*\*\*\*

T,0,0,AND,DCDE(M),GT,0,0,AND,DCDE(M+1),LT,0,0)

GO TO 1000

HAN 3 NEGATIVE DERIVATIVES ON RIGHT SIDE OF POSSIBLE  
 DISREGARDED

0,0,AND,DCDE(M+2),LT,0,0,AND,DCDE(M+3),LT,0,0)

GO TO 1000

(M-1)) 50,50,51  
 (M+1)) 52,52,53

HT BOUNDARIES OF THE PEAK

)) 603,603,608

C,MZ)  
 (MZ)

```

SUBROUTINE SMOOTH(J0,MAN,IC,NCHL,MDATA)
DIMENSION IC(MAN,NCHL),MDATA(NCHL)
J=NCHL-2
DO 1 I=4,J
NSUM=      -3*(IC(J0,I-2)+IC(J0,I+2))+12*(IC(J0,I-1)+IC(J0,I+1))+
117*IC(J0,I)
MDATA(I)=ABS(NSUM)/35
1 CONTINUE
END

```

```

SUBROUTINE DERIV(NCHL,MDATA,DCDE)
DIMENSION MDATA(NCHL),DCDE(NCHL)
J=NCHL-4
DO 2 I=3,J
DCDE1= 2*(MDATA(I+2)-MDATA(I-2))+(MDATA(I+1)-MDATA(I-1))
DCDE(I)=DCDE1/10.0
2 CONTINUE
END

```

```

FUNCTION CENTRD(LB,IRB,M,NCHL,MDATA)
DIMENSION Y(7),YY(7),MDATA(NCHL)
Y2=MDATA(IRB)
Y1=MDATA(LB)
X2=IRB
X1=LB
SLOPE=(Y2-Y1)/(X2-X1)
DO 1 I=1,5
J=M-3
JJ=J+I
Y(I)=SLOPE*(JJ-X1)+Y1
YY(I)=MDATA(JJ)-Y(I)
1 CONTINUE
A21=(2.0*(YY(5)-YY(1))+YY(4)-YY(2))/10.0
A22=(2.0*(YY(1)-YY(3)-YY(5))-YY(2)-YY(4))/14.0
CENTRD=-A21/(2.0*A22)
END

```

```

SUBROUTINE SMOOTH(J0,MAN,IC,NCHL,MDATA)
DIMENSION IC(MAN,NCHL),MDATA(NCHL)
J=NCHL-2
DO 1 I=4,J
NSUM= -3*(IC(J0,I-2)+IC(J0,I+2))+12*(IC(J0,I-1)+IC(J0,I+1))+
117*IC(J0,I)
MDATA(I)=ABS(NSUM)/35
1 CONTINUE
END

```

```

SUBROUTINE DERIV(NCHL,MDATA,DCDE)
DIMENSION MDATA(NCHL),DCDE(NCHL)
J=NCHL-4
DO 2 I=3,J
DCDE1= 2*(MDATA(I+2)-MDATA(I-2))+(MDATA(I+1)-MDATA(I-1))
DCDE(I)=DCDE1/10.0
2 CONTINUE
END

```

```

FUNCTION CENTRD(LB,IRB,M,NCHL,MDATA)
DIMENSION Y(7),YY(7),MDATA(NCHL)
Y2=MDATA(IRB)
Y1=MDATA(LB)
X2=IRB
X1=LB
SLOPE=(Y2-Y1)/(X2-X1)
DO 1 I=1,5
J=M-3
JJ=J+I
Y(I)=SLOPE*(JJ-X1)+Y1
YY(I)=MDATA(JJ)-Y(I)
1 CONTINUE
A21=(2.0*(YY(5)-YY(1))+YY(4)-YY(2))/10.0
A22=(2.0*(YY(1)-YY(3)-YY(5))-YY(2)-YY(4))/14.0
CENTRD=-A21/(2.0*A22)
END

```

1  
J  
4  
M  
H  
M  
H  
  
D  
S  
IM  
JM  
IS  
JH  
SD



```

SUBROUTINE SMOOTH(J0,MAN,IC,NCHL,MDATA)
DIMENSION IC(MAN,NCHL),MDATA(NCHL)
J=NCHL-2
DO 1 I=4,J
NSUM=      -3*(IC(J0,I-2)+IC(J0,I+2))+12*(IC(J0,I-1)+IC(J0,I+1))+
117*IC(J0,I)
MDATA(I)=ABS(NSUM)/35
1 CONTINUE
END

```

```

SUBROUTINE DERIV(NCHL,MDATA,DCDE)
DIMENSION MDATA(NCHL),DCDE(NCHL)
J=NCHL-4
DO 2 I=3,J
DCDE1= 2*(MDATA(I+2)-MDATA(I-2))+(MDATA(I+1)-MDATA(I-1))
DCDE(I)=DCDE1/10.0
2 CONTINUE
END

```

```

FUNCTION CENTRD(LB,IRB,M,NCHL,MDATA)
DIMENSION Y(7),YY(7),MDATA(NCHL)
Y2=MDATA(IRB)
Y1=MDATA(LB)
X2=IRB
X1=LB
SLOPE=(Y2-Y1)/(X2-X1)
DO 1 I=1,5
J=M-3
JJ=J+I
Y(I)=SLOPE*(JJ-X1)+Y1
YY(I)=MDATA(JJ)-Y(I)
1 CONTINUE
A21=(2.0*(YY(5)-YY(1))+YY(4)-YY(2))/10.0
A22=(2.0*(YY(1)-YY(3)-YY(5))-YY(2)-YY(4))/14.0
CENTRD=-A21/(2.0*A22)
END

```

M  
H  
S  
M  
JH  
JH  
J  
J  
JM  
OM  
OM  
OH  
OM  
OH

THAT ISOTOPE

CENTROID  
248.150  
612.856

3246+05

SUBROUTINE SMOOTH(J0,MAN,IC,NCHL,MDATA)

DIMENSION IC(MAN,NCHL),MDATA(NCHL)

J=NCHL-2

DO 1 I=4,J

NSUM= -3\*(IC(J0,I-2)+IC(J0,I+2))+12\*(IC(J0,I-1)+IC(J0,I+1))+

117\*IC(J0,I)

MDATA(I)=ABS(NSUM)/35

1 CONTINUE

END

SUBROUTINE DERIV(NCHL,MDATA,DCDE)

DIMENSION MDATA(NCHL),DCDE(NCHL)

J=NCHL-4

DO 2 I=3,J

DCDEI= 2\*(MDATA(I+2)-MDATA(I-2))+(MDATA(I+1)-MDATA(I-1))

DCDE(I)=DCDEI/10.0

2 CONTINUE

END

FUNCTION CENTRD(LB,IRB,M,NCHL,MDATA)

DIMENSION Y(7),YY(7),MDATA(NCHL)

Y2=MDATA(IRB)

Y1=MDATA(LB)

X2=IRB

X1=LB

SLOPE=(Y2-Y1)/(X2-X1)

DO 1 I=1,5

J=M-3

JJ=J+1

Y(I)=SLOPE\*(JJ-X1)+Y1

YY(I)=MDATA(JJ)-Y(I)

CONTINUE

A2I=(2.0\*(YY(5)-YY(1))+YY(4)-YY(2))/10.0

A22=(2.0\*(YY(1)-YY(3)-YY(5))-YY(2)-YY(4))/14.0

CENTRD=-A2I/(2.0\*A22)

END

ID	% DIFFERENCE
21	
13	
,98	
,92	1.8022
,92	1.5666
3.81	
2.58	
0.02	.2953
33.21	.5471
30.28	.2496
48.21	.6557
48.21	.0254
248.21	.0919
269.00	.0637
300.53	.2538
300.53	.0047
375.14	.4127
375.14	.0506
399.28	.0456
413.87	.067
447.04	
657.92	.041
701.23	
719.83	.17
732.81	.06
831.64	.0
914.84	
936.12	
977.93	
991.30	

CENTROID	LFTBND	RGHTBND	BASE AREA	PEAK AREA
73.21	71	77	22397.5	471.5
89.13	87	97	35428.5	617.5
99.98	97	104	22707.0	459.0
108.92	104	114	35788.5	2264.5
118.81	114	124	36805.5	1378.5
132.58	131	139	25081.0	522.0
170.02	168	172	8841.0	1550.0
183.21	181	186	11386.0	349.0
200.28	198	203	10792.0	344.0
248.21	246	251	9960.0	3172.0
269.00	267	271	7380.0	688.0
300.53	297	304	14463.0	559.0
375.14	373	378	9648.0	681.0
399.28	397	402	10046.0	413.0
413.87	411	417	13070.0	963.0
447.04	442	450	18686.5	445.5
657.92	655	661	3717.5	1448/3.5
701.23	697	704	4332.0	347.0
719.83	715	723	4963.0	239.0
732.81	729	736	4401.0	532.0
831.64	829	834	3006.0	23651.0
914.84	912	918	5007.5	251.5
936.12	933	939	5187.5	241.5
977.93	975	981	5575.0	245.0
991.30	989	1001	12028.5	369.5

## APPENDIX B

### Description of Macon Demonstration Test as Mailed to Participants

# ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

September 13, 1972

Enclosed is a short description of the demonstration in which you participated on August 8 at the Macon treatment plant. The results show that the basin was operating very efficiently at that time, although flow was not equally divided between the four sections.

Your presence was appreciated and it is hoped that this demonstration will encourage you to use the same technique in your own plant if the need should ever arise.

If I can be of assistance in any way, don't hesitate to call on me.

Yours truly,

T. F. Craft, Ph.D.  
Senior Research Scientist

TFC/mw

August 15, 1972

Demonstration of Tracer Technique

Macon, Georgia August 8, 1972

The primary sedimentation tank at the Macon wastewater treatment plant is divided into four separate compartments, each fed from a single common channel. No particular difficulty has been encountered with the operation of this process, but the plant operators were aware that flow was not evenly divided among the separate compartments. They had investigated this matter earlier with a dye tracer, some of which passed through the basin in about 25 minutes.

The August 8, 1972 demonstration was held to demonstrate a technique being developed by The Engineering Experiment Station, Georgia Institute of Technology. This work is supported by the U.S. Atomic Energy Commission.

The tracer consisted of 40 grams of the rare element indium which is not found in wastewater. It was dissolved in nitric acid and diluted with water to about one gallon. A pound of bright red dye, Rhodine 6B, dissolved in a gallon of water was also used to visually indicate the presence of the tracer element. These solutions were poured into the plant influent channel where the flow is distributed among the four compartments. On this date the basin was operating very efficiently, and no dye became visible in the effluent for nearly an hour. Samples were collected at frequent intervals, and subsequently analyzed for indium content. The analyses were carried out at Georgia Tech by the neutron activation technique, utilizing the Georgia Tech Research Reactor. Duplicate samples were examined, and the results are shown in Figures 1 and 2. It is apparent that the peak concentration appeared in the effluent of the southwest quadrant at about 70 minutes. The maximum in the southeast sector appeared about 8 minutes later. Less tracer entered the other compartments, and no distinct peak was observed.

From these results it appears that insufficient dye was used to produce the very sharp color change that is most easily recognized. When a basin is operating efficiently more dye is required because the entire contents of the basin must become colored. When a density current is present, only the moving fraction of the volume requires color. As pointed out, it is not mandatory to include any dye with the indium. The color simply indicates the progress of the tracer and reduces the number of samples required.

It is therefore concluded that the four compartments of the basin were operating without appreciable density currents, but flow was not evenly distributed among the four compartments.



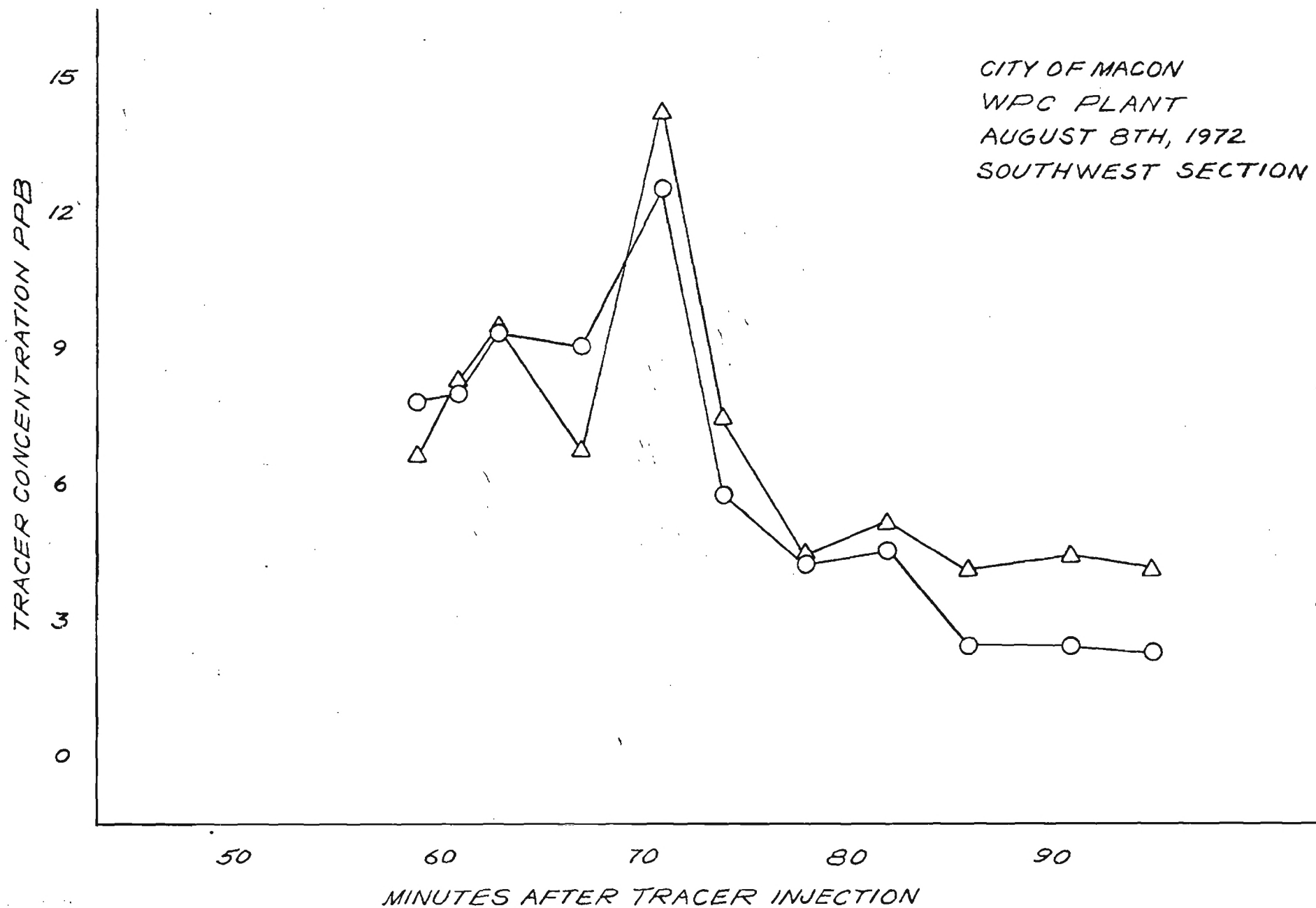


Figure 1. Tracer concentration in primary sedimentation basin, southwest section.

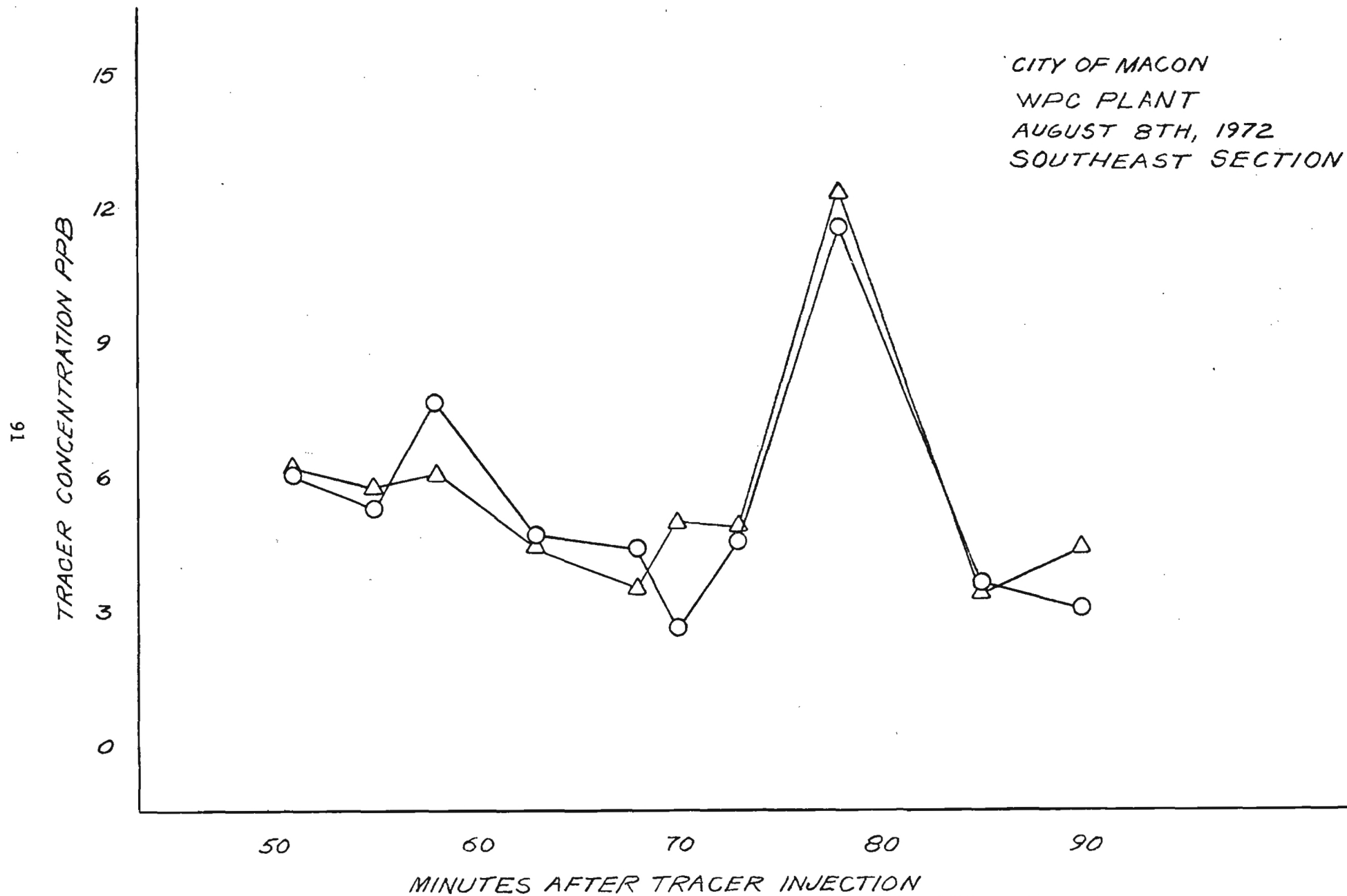


Figure 2. Tracer concentration in primary sedimentation basin, southeast section.